Investigations by the Geological Survey of Canada in Manitoba and Saskatchewan during the 1984-1989 Mineral Development Agreements

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Investigations by the Geological Survey of Canada in Manitoba and Saskatchewan during the 1984-1989 Mineral Development Agreements

compiled
by

A.G. Galley

November, 1989

**Saskatchewan
Energy and Mines**

**Manitoba
Energy and Mines**

Caveat Lector: The manuscripts contained in this volume have been critically reviewed by Geological Survey of Canada staff, but have not undergone a thorough Geological Survey editing.

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Cover description: Auriferous quartz vein system crosscutting Amisk Group mafic volcaniclastic rocks within a dip-slip fault zone. Main Zone, Snow Lake Mines Ltd., Snow Lake, Manitoba

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INTRODUCTION

A.G. Galley

In early 1984 the Federal cabinet, and those of Manitoba and Saskatchewan approved two separate Mineral Development Agreements (MDA's) as subagreements to the umbrella Economic and Regional Development Agreements (ERDA). Under the terms of the subagreements, the Federal and Provincial governments came to a cost-sharing arrangement (60:40 and 50:50 federal-provincial split for Manitoba and Saskatchewan respectively) through which it was agreed to spend a total of $24.7 million in Manitoba and $6.8 million in Saskatchewan.
The objectives of the MDA were to:
a) Establish a framework for implementation of programs that will strengthen and diversify the mineral resource base of the provincial economy.
b) To increase mineral exploration and the development of mineral resources in the province.
c) To assist in a more effective assessment and utilization of the provinces mineral resources.
Programs under the MDAs were divided into four sectors: ‘A' - Geoscientific studies, ‘B' - Mining and mineral technology research and development, ‘C' - Development and marketing studies, and ‘D' Public information, evaluation and administration. The projects covered by this summary volume were from the Sector A program.

The GSC MDA programs in Manitoba and Saskatchewan concentrated in the Precambrian Shield, and along the Shield margin. They included a broad spectrum of projects that involved most of the geoscientific disciplines in which the GSC has an expertise.

Airborne vertical gradient and total field magnetometer surveys were completed over parts of the LaRonge and Flin Flon region of Saskatchewan, and in the Lynn Lake, Flin Flon-Snow Lake and Bissett regions of Manitoba. Parts of three 1:250 000 NTS sheets covering the Paleozoic rocks along the edge of the Shield were flown in both provinces. An airborne electromagnetic survey was flown over part of the Lynn Lake region.

Regional Lake sediment and water surveys completed coverage of the area in Saskatchewan south and east of the Athabasca Basin, and in Manitoba the survey covered parts of the Shield north of 52° that did not contain extensive deposits of Lake Agassiz clay. The project included re-analysis of older regional survey samples and detailed follow-up surveys over certain greenstone belts. Studies were carried out on the ability of lake sediments to reflect metal concentrations accumulated from the lakes drainage basin.

The Terrain Sciences Division of the GSC restricted its program to Manitoba, where a regional till geochemical program was incorporated with surficial geology mapping. Studies were completed on Quaternary ice flow patterns and the effects of till composition on concentrating metals aquired from the glaciated terrane.

Precambrian geological investigations were divided into two areas: the first concentrated on unravelling the tectonic history of the Early Proterozoic terranes of the Trans-Hudson Orogen and its margin with the Superior Province. This involved extensive geochronological sampling of greenstone belts and intervening high grade metamorphic terranes. Dovetailed with this were several studies on the metamorphic history of this part of the Shield, which included mapping the Flin Flon-Kisseynew margin in Saskatchewan, the Lynn Lake-Kisseynew margin in Manitoba and structural studies in the Thompson fold belt.

The second area of Precambrain study was mapping of the sub-Phanerozoic Shield south of the Flin Flon belt. This study coordinated work by geologists and geophyscists from both federal and provincial surveys to decipher the nature of the Precambrian strata below 100 to 150 metres of limestone, thereby allowing exploration companies to better evaluate the potential of these hidden rocks.

Mineral deposit investigations comprised three topics: a) structural control of gold deposits, b) metal associations with mafic-ultramafic intrusions, and c) application of remote sensing to mineral exploration. Gold studies took place in the Flin Flon belt of both Manitoba and Saskatchewan, the LaRonge belt of Saskatchewan and in the Rice Lake-Beresford region of Manitoba. These studies produced maps at various regional scales that show the spatial association of gold occurrences with large fault systems.

Mafic-ultramafic investigations incorporated studies in the Archean Superior Province of Manitoba, the transitional Archean-Proterozoic terranes of Saskatchewan and in the Early Proterozoic Trans-Hudson Orogen that extends across both provinces. Layered and composite mafic-ultramafic intrusions were mapped and sampled to evaluate the potential for nickel-copper, PGE, chrome, titanium and vanadium mineralization.

The remote sensing project evaluated the use of satellite imagery in locating regions of high mineral potential. The project not only tested the possiblilty of identifying stressed vegetation near anomalous concentrations of metals, but also attempted to integrate the various types of airborne geophysical, regional geochemical and remotely sensed data available for the Lynn Lake region.

The success of the MDA geoscience programs in Manitoba and Saskatchewan must be weighed by the ability of the federal and provincial surveys to transfer the data colllected, and ideas formulated, during the MDA's to the mineral industry. To date, the GSC has released 354 maps related to airborne geophysics, regional geochemistry, till geochemistry, mineral and geological investigations. Over 150 reports have been published in government annual summaries, and 17 papers published in outside journals and conference volumes. 85 poster displays and 51 papers were presented at various government and industry sponsored meetings. A bibliography of outputs from the GSC is included in the back of this volume (Appendices I and II), and will be updated a year from now following completion of the final publications from each project.

The MDAs have also resulted in the development of closer ties between the federal and provincial surveys, and between the GSC and the mineral industry. It has been agreed by the two levels of goverment that standing commitees be appointed through which the federal and provincial surveys will be kept informed of proposed geoscience programs. This will eliminate duplication and promote cooperative activites, thereby increasing efficiency in serving the mineral industry. The GSC will continue its participation in the industrial liason committees in order to in touch with the current needs of the mineral industry.

Acknowledgements

The appendices containing the outputs for the two MDA's was compiled by Dan Richardson of the Mineral Resources Division. Dave Garson of the Mineral Resources Division showed great perserverance in aquainting me with the intricacies of desk-top publishing. I am very grateful to both of these gentleman for their assistance.

METAMORPHOSED ALTERATION ZONES

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INTRODUCTION

Hydrothermally altered rocks, some associated with sulphide mineralization, are widespread in the Flin Flon and Lynn Lake volcanic belts. They are also found in the area of Kisseynew and Kississing Lakes, thought to be a metamorphosed portion of the Flin Flon volcanic belt (Ashton, 1989). Several examples at different metamorphic grade were studied and abstracts or summaries are provided:

1. Biotite-staurolite-aluminum silicate zone:

    Linda deposit (Zaleski, 1989)
    Nicoba deposit (Barham, 1985)
    North Cook Lake (Froese et al., 1989)

2. Biotite-sillimanite-almandine zone:

    Osborne Lake deposit (Bristol and Froese, 1989)
    New Fox occurrence (Barham, 1987)
    Wolverton Lake area (Froese, 1989)
    Star Lake area (Leroux, 1989)

The altered compositions give rise to mineral assemblages unusual for volcanic rocks, i.e. "mineralogical anomalies" (Carpenter and Allard, 1982) potentially useful in exploration. Metamorphic mineral assemblages reflect pre-metamorphic hydrothermal alteration and metamorphic grade. The outstanding alteration effect is the removal of Ca and Na. In these depleted rocks, three compositional types of alteration can be recognized - aluminous,potassic and ferromagnesian, corresponding to the formation of large amounts of clay minerals, sericite and chlorite. The Fe/Mg ratio of chlorite can be variable; some chlorite in alteration zones is Fe-rich (Embley et al. 1988). Most minerals produced by subsequent metamorphism can be shown on the AKF diagram of metamorphic petrology. In addition to these minerals, gahnite is common in metamorphosed altered rocks. Gahnite and zinc-bearing staurolite are indicators of zinc in sulphur - poor rocks and have been proposed as exploration tools (Spry and Scott, 1986; Trembath,1986). Because gahnite incorporates Fe and Mg, phase relations of gahnite and other ferromagnesian minerals are complicated; they have been considered by Zaleski (1989) and Froese et al (1989).

Alteration types may be interpreted in terms of properties of hydrothermal solution. From a stability diagram presented by Riverin and Hodgson (1980), based on the thermodynamic data of Helgeson (1969), it is apparent that, at constant activity of K^+ and Mg^{++}, chlorite reflects a higher temperature and/or higher pH than sericite/kaolinite.

Zonation in metamorphosed alteration is preserved to varying degrees. In the Linda deposit, a distal chloritic alteration zone and a proximal sericitic alteration zone are distinguihsed (Zaleski 1989). At the North Cook Lake deposit (Froese et al. 1989) ferromagnesian alteration is more restricted than aluminous alteration. Mineralization is more closely associated with ferromagnesian alteration. On a more regional scale, there is no apparent zonation of aluminous and ferromagnesian alteration in the Wolverton Lake area (Froese, 1989) and a preference of mineralization for a particular alteration type is not obvious.

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THE GEOLOGY OF THE NICOBA ZN-CU DEPOSIT, LYNN LAKE, MANITOBA: PRELIMINARY RESULTS

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(Abstract from Geological Survey of Canada Paper 85-1A)

The Nicoba Zn-Cu deposit, located in the Lynn Lake Greenstone Belt, is hosted by pyroclastic and epiclastic rocks of the Lynn Lake Rhyolitic Complex. Footwall lithologies contain lenticular units of felsic pyroclastic flows, volcanic breccia with mafic matrix, and other fragmental rocks. A massive porphyritic tuff forms the hanging wall. Thin stratiform layers of sulphide are interlayered with chemical and detrital sediments. Hydrothermal alteration, and subsequent medium-grade metamorphism have resulted in a thick, nearly conformable footwall layer of porphyroblastic aluminus schist depleted in Na_2O and CaO. Minerals commonly developed in the schist include Mg-biotite, sericite, andalusite, kyanite, staurolite, plagioclase, garnet and gahnite. The schist layer is enveloped by sericitized felsic rocks. Metamorphosed equivalents of intensely chloritized rocks have not been identified.

GEOLOGY OF THE NEW FOX ALTERATION ZONE LAURIE LAKE, MANITOBA.

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In the Laurie Lake-Dunphry lakes area of the Lynn Lake Greenstone Belt, unusual rocks characterized by coarse-grained garnet, cordierite, orthoamphibole, and in some cases sillimanite and staurolite, occur. At the New Fox Alteration Zone, these rocks represent metasomatized and subsequently metamorphosed equivalents of mostly mafic to intermediate, hornblende-bearing volcanic rocks, but are also developed in more felsic, hornblende-bearing sedimentary and volcaniclastic rocks. Weakly altered to unaltered host rocks are characterized by calcic minerals including hornblende, epidote, titanite and andesine. The predominant type of altered rocks forms a stratiform layer characterized by calcium-poor mineral assemblages rich in gedrite, garnet and cordierite. Hornblende-bearing rocks are everywhere separated from Ca-poor gedrite-bearing rocks by cummingtonite-andesine rocks intermediate in calcium content. The progressive destruction of primary volcanic structures provides compelling evidence for derivation of the Ca-poor rocks by in situ hydrothermal alteration. Siliceous alteration and Ca-enriched alteration, containing clinopyroxene, are developed at the margins of the main stratiform zone of Ca-depleted rocks.

Mineral analyses from thirteen rocks show that the distribution equation valid for ideal binary solutions:

$$KD= (XMgA/ (1-XMgA)) ((1-XMgB)/XMgB)$$

where $XMg=Mg/(Mg+Fe^{+2})$ and A and B are ferromagnesian phases, adequately describes the distribution of Mg and Fe^{2+}. Amongst the five ferromagnesian phases cordierite, biotite, gedrite, cummingtonite and garnet, two naturally occurring, four phase assemblages have the following distribution relationships:

XMg:

cordierite1.81>biotite1.46>gedrite3.63>garnet
biotite1.18>cummingtonite1.38>gedrite3.63>garnet

where the numbers refer to the distribution coefficient (KD).

In hornblende-cummingtonite assemblages, KD varies with XMg which decreases with increased Mg tschermakite substitution ($Al^{IV}Al^{VI}=MgSi$) in hornblende. Considering Fe-rich mineral assemblages with garnet, the distribution relationships are:

XMg:

biotite~cummingtonite1.16>hornblende4.45>garnet

Mineral assemblages in the New Fox Alteration Zone reflect medium-grade metamorphism. Deduced conditions correspond to those of the sillimanite-muscovite zone and are consistent with a regional northeast-southwest increase in metamorphic grade. Garnet-biotite and garnet-cordierite exchange thermometry and qualitative estimates of pressure and X_{H_2O} give the following conditions of metamorphism:

T~600oC
P=4-5 kb
XH20~1

Suitable quartz-chlorite protoliths for the Fe-rich and Ca-depleted rocks typical of the New Fox Alteration Zone are observed in the geologic record and are being formed presently in active hydrothermal systems. A brief review of current basalt-seawater experiments and observations of active geothermal systems suggests that unmodified seawater would not be capable of producing the required iron-rich chloritic protoliths.

HIGHLY METAMORPHOSED ALTERED ROCKS ASSOCIATED WITH THE OSBORNE LAKE VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT

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(abstract of paper in Canadian Mineralogist, December 1989)

The Osborne Lake Cu-Zn orebody in the northeastern part of the Snow Lake area of Manitoba is formed by a single lense of massive sulfide mineralization enclosed in felsic volcaniclastic rocks. The orebody and host rocks have been metamorphosed to the highest grade of regional metamorphism in the Snow Lake area, corresponding to the biotite-sillimanite-almandine zone. Wallrock alteration is reflected in the depletion of Ca and Na and the enrichment of Mg and Fe. Alteration zones are characterized by cordierite, anthophyllite, staurolite and, more rarely, coarse-grained chlorite and phlogopite. Gahnite commonly enclosed by cordierite, is present in some altered rocks. These highly metamorphosed altered rocks probably represent original zones of chloritization typically associated with volcanogenic massive sulfide deposits.

ALTERATION IN THE VICINITY OF WOLVERTON LAKE, SNOW LAKE AREA

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Near Wolverton Lake, a few occurrences of alteration minerals were noted by Froese and Moore (1980). Further work has documented more extensive alteration in felsic and mafic volcanic rocks. The metamorphic grade in the area corresponds to the biotite-sillimanite-almandine zone. Stable mineral assemblages are shown on an AKF diagram (Figure 1). Because FeO and MgO have been grouped as one component, almandine is a common additional phase. The association of cordierite, sillimanite, and almandine suggests that small grains of staurolite are relics. Two types of alteration are recognized in the area (Figure 2). Ferromagnesian alteration is characterized by the assemblasge biotite-anthophyllite +/- cordierite. The common presence of almandine indicates intermediate Fe/Mg ratios. Aluminous alteration is more restricted in occurrence. It is marked by the assemblage biotite-sillimanite and /or cordierite. Green spinel, probably gahnite, is a common accessory mineral. The two alteration types may alternate over distances of a few metres. Muscovite-bearing rocks are rare and potassic alteration appears to be absent. Disseminated pyrite and pyrrhotite are present in both ferromagnesian and aluminous alteration, showing no obvious preference. Sulphides also occur in unaltered felsic rocks.

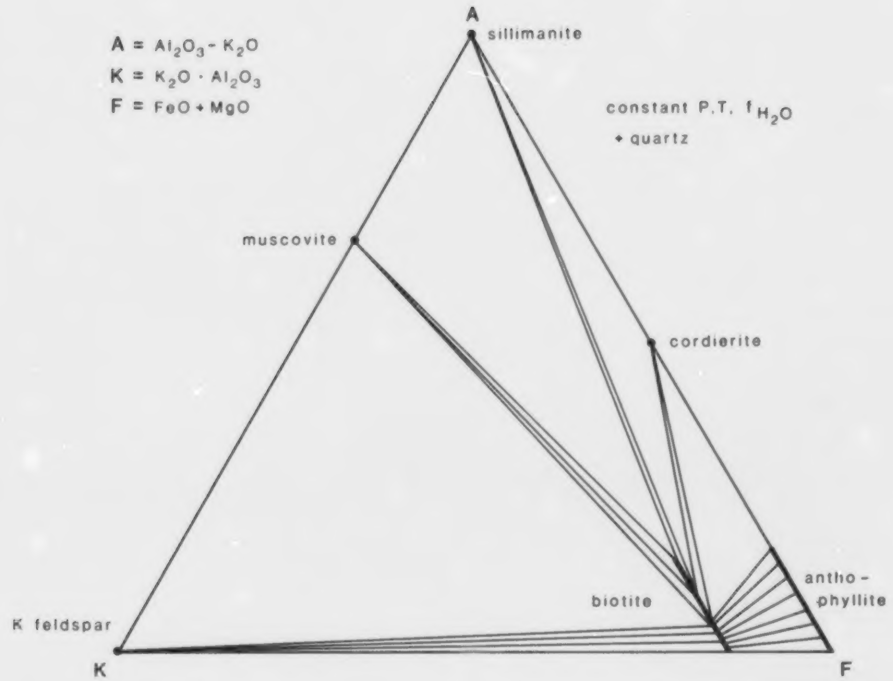
A = $Al_2O_3 - K_2O$
K = $K_2O \cdot Al_2O_3$
F = $FeO + MgO$
A
sillimanite
constant P,T, f_{H_2O}
+ quartz
muscovite
cordierite
antho-phyllite
biotite
K feldspar
K
F

Figure 1. AFK diagram for rocks from the Wolverton Lake area.

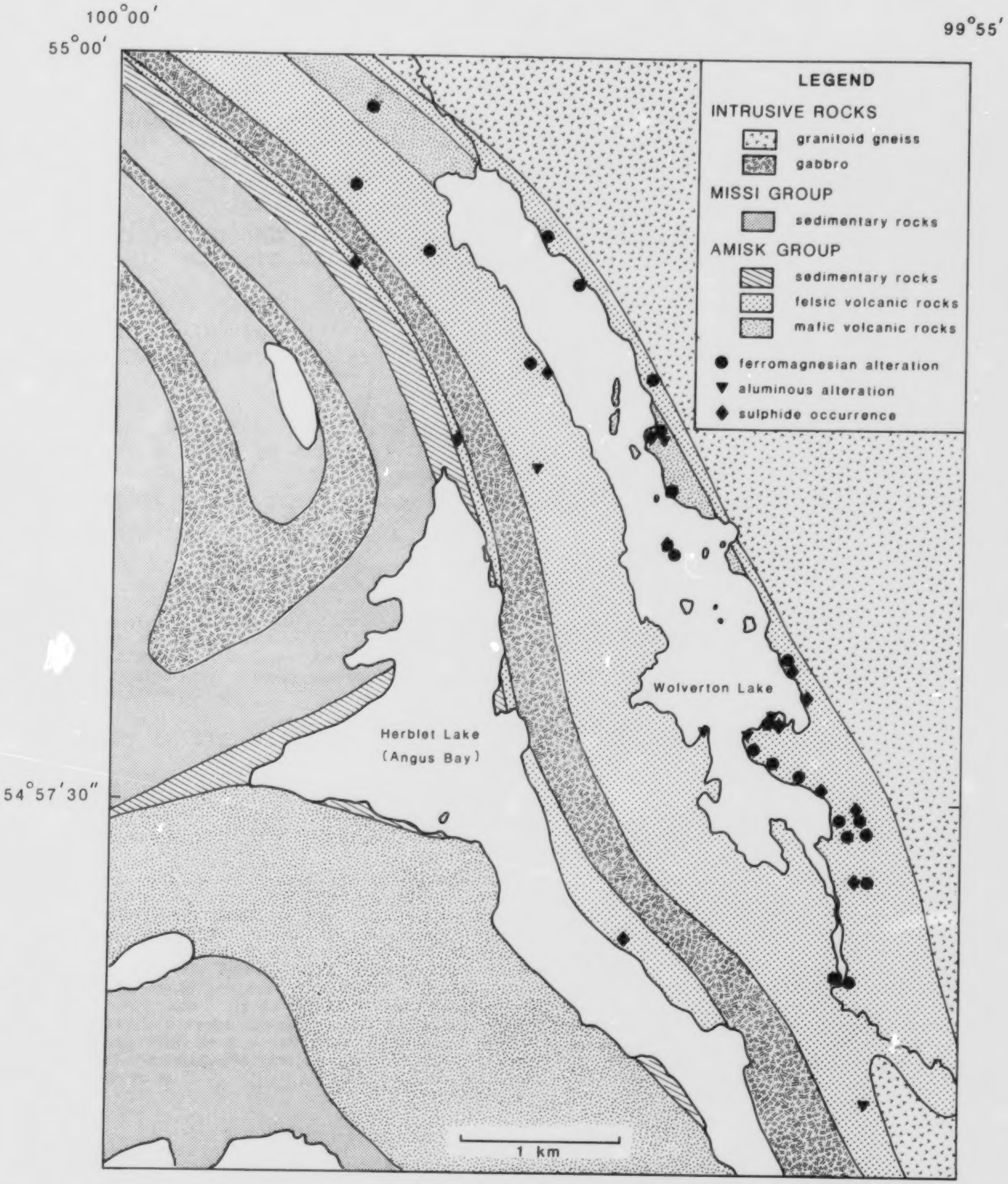
100°00′
55°00′
99°55′
54°57′30″
LEGEND
INTRUSIVE ROCKS
granitoid gneiss
gabbro
MISSI GROUP
sedimentary rocks
AMISK GROUP
sedimentary rocks
felsic volcanic rocks
mafic volcanic rocks
ferromagnesian alteration
aluminous alteration
sulphide occurrence
Wolverton Lake
Herblet Lake
(Angus Bay)
1 km

Figure 2. Occurrences of alteration in the Wolverton Lake area.

MINERALOGICAL AND GEOCHEMICAL INVESTIGATION OF THE CORDIERITE-ANTHOPHYLLITE ROCKS AT STAR LAKE, NEAR SHERRIDON, MANITOBA

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The Sherridon Group, a stratigraphic unit of the Kisseynew gneiss belt, near Sherridon, Manitoba is typically dominated by quartz-rich gneisses. Discontinuous lenses of cordierite-anthophyllite rocks, the focus of the present study, occur within these quartz-biotite gneiss units. These cordierite-anthophyllite gneisses are extremely coarse-grained in places, and are spatially associated with barren (Star Lake) and sulfide-mineralized zones (Sherridon; Elken Lake). The present chemical composition of the Star Lake-Elken Lake gneisses indicates hydrothermal alteration of a basaltic progenitor producing chlorite-rich alteration pipes. This alteration involves a depletion in alkali and alkaline earth elements with an apparent enrichment in Al and Mg as a function of constant summation. These chemical modifications are the result of reactions between heated seawater and basaltic rocks of the crust. A modern analogue of the Sherridon Group environment might be the shelf and slope deposits of modern island arcs.

RELATIONSHIP BETWEEN DEFORMATION AND METAMORPHISM AT THE LINDA VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT, SNOW LAKE, MANITOBA.

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The complex structure and mineralogy of the Linda volcanogenic massive sulphide deposit are the result of polyphase dynamometamorphism superimposed on primary sulphide mineralization and associated hydrothermal alteration. Outcrop mapping and drill-core logging elucidated the 3-dimensional configuration of the deposit. Microstructural and paragenetic relationships, mineral chemistry, and wholerock geochemistry constrain its petrogenesis and its significance to the structural and metamorphic history of the Snow Lake region.

At the Linda deposit, two discrete zones of Fe-Mg alteration occur in felsic rocks of the stratigraphic footwall. The proximal alteration zone consists mainly of stratabound and stratiform mineralization resulting from the accumulation of chemical sediments in a topographic depression on the down-thrown side of a syn-volcanic fault. The distal alteration zone is hosted by felsic volcanic rocks lower in the stratigraphic sequence and may represent subsurface alteration.

The Linda deposit lies in highly strained overturned rocks on one flank of the Anderson Bay structure, which marks a change in stratigraphic facing direction. The Anderson Bay structure is transected by S1 and S2 cleavages. Syn-D2 porphyroblasts at the Linda deposit record early sinistral S1/S2 cleavage vergence; phyllosilicate minerals in the matrix define dextral S1/S2 cleavage vergence resulting from late D2 (or D3) reactivation of the S1 cleavage. The reactivation has regional significance.

Metamorphic paragenesis at the Linda deposit apparently spans three zones of regional metamorphism. The bulk-rock composition of the altered protolith allowed the crystallization of manganiferous garnet, zincian staurolite and F-rich biotite, thus expanding the stability fields of parageneses containing these minerals. A pressure-temperature-time trajectory is recorded by syn-D1 kyanite and by syn-D2 amphibolite-facies assemblages, which represent the culmination of metamorphism. Sphalerite geobarometry yields a pressure of about 5 kb; the maximum temperature is limited to about 550oC by the coexistence of margarite + quartz. Sulphide-silicate-oxide equilibria can be modelled in a petrogenetic grid in the $SiO_2-Al_2O_3-FeO-MgO-ZnO-K_2O-H_2O-S_2-O_2$ system at fixed pressure and temperature. Metamorphic desulphidation of sphalerite released Zn to staurolite and gahnite. The largest massive sulphide body consists of pyrite and calcite, the latter introduced during post-tectonic synmetamorphic metasomatism.

DEFORMATION OF QUARTZO-FELDSPATHIC GNEISSES IN THE THOMPSON BELT, MANITOBA.

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Early Proterozoic rocks and Archean gneisses of the Thompson Belt, east of the Churchill-Superior Province boundary, record the history of the Hudsonian Orogeny in this area. This study examines the deformation of the quartzo-feldspathic gneisses along a transect across the Thompson Belt. Foliation and lineation data and the analysis of kinematic indicators along this transect show that:

1. the Thompson Belt has been an area of predominantly dip-slip movement for the ductile deformation history recorded in the rocks;

2. the prevailing sense of shear was Superior-side-up, Churchill-side-down;

3. the shearing juxtaposed rocks of progressively higher metamorphic grade towards the southeast, away from the Churchill-Superior boundary;

4. there appears to have been a period of movement at the later stages of the orogeny in which the sense of movement was Churchill-side-up.

Quartz c-axis fabrics can be used as kinematic indicators of sense of progressive simple shear in coarse grained quartzo-feldspathic gneisses and confirm the sense of shear obtained by other kinematic indicators. There are consistent variations in quartz c-axis fabric types across the Thompson Belt. These variations can be used to outline a region in which the last episode was one of progressive pure shear. Quartz c-axis fabrics in rocks which were deformed during the Churchill-side-up episode are distinctive and can be correlated despite variations in quartz grain size and texture. Separate quartz c-axis types can be explained by the activation of distinct glide systems within quartz at different stages within the orogeny. Variations in quartz c-axis types across the Thompson Belt are similar to the variations in quartz c-axis types observed in the Saxony granulites.

The detailed examination of quartz ribbons shows that c-axis fabrics may be heterogeneous on the scale of the thin section. In some gneisses, individual domains within a single thin section do not mimic the fabric of the entire section. The size of the domains is controlled by the absence or presence of quartz ribbons. A model is presented in which a large ribbon grain can grow out of a patch of quartz if it is able to minimize its internal strain energy by deforming on one favourably oriented "easy" glide system. Alternatively, some ribbon grains may originate as pressure shadows on the low-pressure side of feldspar grains, suggesting that metamorphic segregation may be an important deformation in high grade gneisses.

ALTERATION ZONES, STRUCTURE, AND METAMORPHISM OF THE LAURIE LAKE AREA

Stephen L. Jackson
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INTRODUCTION

The Laurie Lake Area (Figure 1) in northern Manitoba contains Early Proterozoic rocks of the Churchill Province that belong to both the Lynn Lake Metavolcanic Belt and the Kisseynew Metasedimentary Belt (Milligan, 1960; Gilbert et al., 1980). This study focussed on the structure and metamorphism of this area. However, mapping during the course of the study also established the presence of some previously unrecognized alteration zones. Such zones are known to be associated with sulphide deposits (e.g. the Fox Mine and Lar deposit) and, because of their potential economic significance, are discussed below. Data, observations, and conclusions of this study have been documented in detail by Jackson and Gordon (1985, 1986) and Jackson (1988). Some of the principal results are outlined below.

METAMORPHOSED ALTERATION ZONES (METAMORPHOSED "FEMGAL" ROCKS)

This rock-type is known to local geologists as "alteration", "alteration zone", or "metamorphosed alteration" because its chemical composition does not correspond to that of any common rock type (e.g. Eskola, 1914; Tilley and Fleet, 1930; Froese, 1969). These rocks are enriched in Fe and/or Mg, and Al (hence the acronym FEMGAL) and depleted in Ca, Na and K relative to unaltered protolith rocks (e.g. Eskola, 1914; Tilley and Fleet, 1930). Coexisting metamorphic minerals that reflect the unusual composition include various combinations of cordierite, gedrite, garnet, cummingtonite, sillimanite, staurolite, hornblende, plagioclase, magnetite, sulphides, and quartz. Biotite, if present, is the only K-bearing mineral. The distribution of these rocks is shown in Figure 2 (see references in Table 1).

One of the zones recognized in this study, south of Eager Lake (zone 13 of Figure 2), is the largest known metamorphosed alteration zone in the Lynn Lake Area. A sketch map of a portion of this zone is provided (Figure 3).

The metamorphosed FEMGAL rocks are classified into two groups. The first group consists of those zones associated with mafic to intermediate metavolcanic rocks and aluminous K-poor metasediments (zones 17 and 1 through 10 of Figure 2). The second group consists of those zones associated with high-grade Sickle metasediments and minor metavolcanic rocks and amphibolites (zones 11 through 14 of Figure 2).

Primary volcanic features and/or progression from unaltered metavolcanic rocks to Crd-Ged-bearing rocks are observed in zones 1 (Elliot and Appleyard, 1985), 4 (this study; see caption to Figure 2), and 6 (Barham, 1987) and the Fox Mine Area. One interpretation, consistent with the available data for zones 1 through 10, of metamorphosed FEMGAL rocks intimately associated with metavolcanic rocks is that they represent metamorphosed chlorite-quartz ± clay zones that developed in situ during pre-metamorphic alteration of the volcanic and associated rocks (e.g. Tilley and Fleet, 1930; Froese, 1969; and Barham, 1987; zone 6 of Figure 2).

The metamorphosed FEMGAL rocks south of Eager Lake are laterally continuous and occur in a high-grade, predominantly metasedimentary succession with amphibolites and metavolcanic rocks. Mineral assemblages within this zone (Figure 3) are similar to those of the first group of FEMGAL rocks. Therefore, this zone is also interpreted as a metamorphosed chlorite-quartz ± clay horizon. The presence of metavolcanic rocks may indicate that this zone also formed by in situ hydrothermal alteration; however, identification of structures and/or textures proving such an origin was not possible owing to the high-grade and high-strain state of the rocks. The lateral continuity of the zone may indicate that the original chlorite-quartz ± clay material was deposited as a layer, perhaps as reworked, previously altered material or as volcanic ash deposited and altered in water.

STRUCTURAL GEOLOGY

The area is divisible into four main lithostructural domains (Figure 4). Domain 1, consisting largely of metavolcanic rocks and metagreywacke, contains steep-dipping, relatively smooth-trending, layer-parallel foliations and steep-plunging lineations. Domain 2, consisting chiefly of Sickle Group

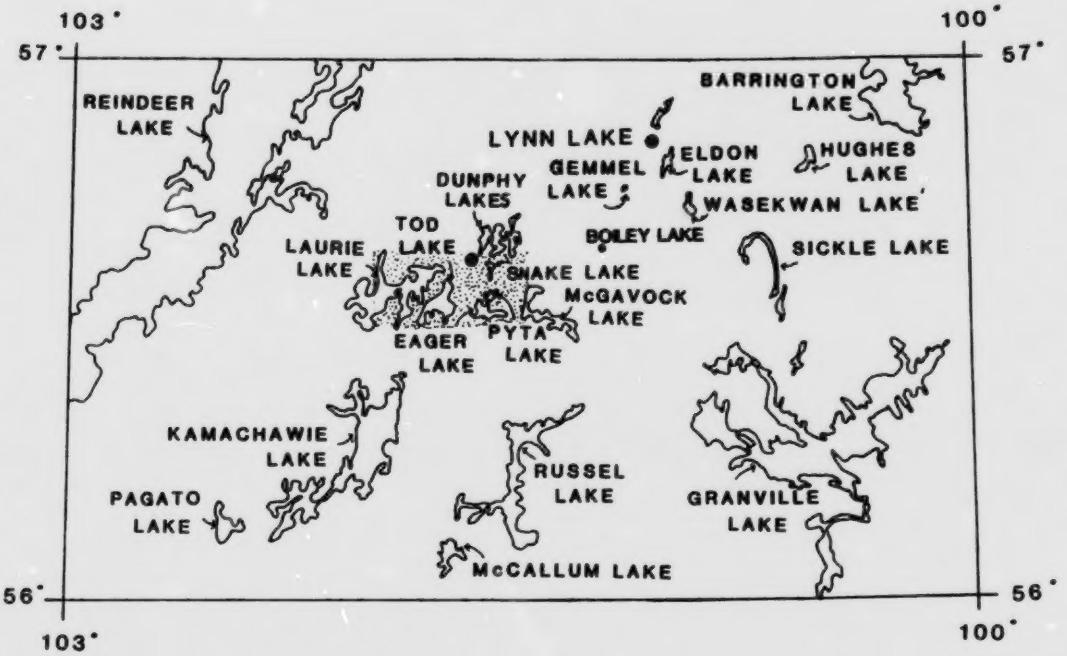
103°
100°
57°
57°
56°
56°
103°
100°
REINDEER LAKE
BARRINGTON LAKE
LYNN LAKE
ELDON LAKE
HUGHES LAKE
GEMMEL LAKE
DUNPHY LAKES
WASEKWAN LAKE
TOD LAKE
LAURIE LAKE
BOILEY LAKE
SICKLE LAKE
SNAKE LAKE
McGAVOCK LAKE
EAGER LAKE
PYTA LAKE
KAMACHAWIE LAKE
RUSSEL LAKE
PAGATO LAKE
GRANVILLE LAKE
McCALLUM LAKE

Figure 1. Location map of the Laurie Lake Area (stippled region)

metasediments, contains east northeast-trending, gently-plunging folds of a conglomerate layer that is overturned to the south. In the southern part of Domain 2 is a map-scale fold of sheath geometry that opens downwards to the north and plunges east northeast. Domain 3 consists of highly attenuated, moderately NE-plunging cylinder-shaped folds of migmatized Wasekwan Group and Sickle Group metasediments. Domain 4 is underlain largely by tonalite intrusions having north-dipping foliations. Domain boundaries are marked by structural discontinuities.

Two major episodes of deformation can account for the observed structural geology. One episode resulted in development of a transposition foliation and the other resulted in the deformation of the transposed layering and foliation into the present map pattern. The second deformation involved south southwest- to south-directed ductile thrusting, after the development of the layer-parallel foliation, of the Lynn Lake Metavolcanic Belt over the adjacent Kisseynew Metasedimentary Gneiss Belt. Metamorphism was synchronous with, but outlasted, the main deformations.

METAMORPHISM

A regional metamorphic gradient is preserved within the Laurie Lake Area. In response to increasing degree of metamorphism the most significant changes were:

1) In K-feldspar-bearing quartzofeldspathic rocks,
    i) sillimanite appeared
    ii) granitic leucosomes appeared and increased in abundance

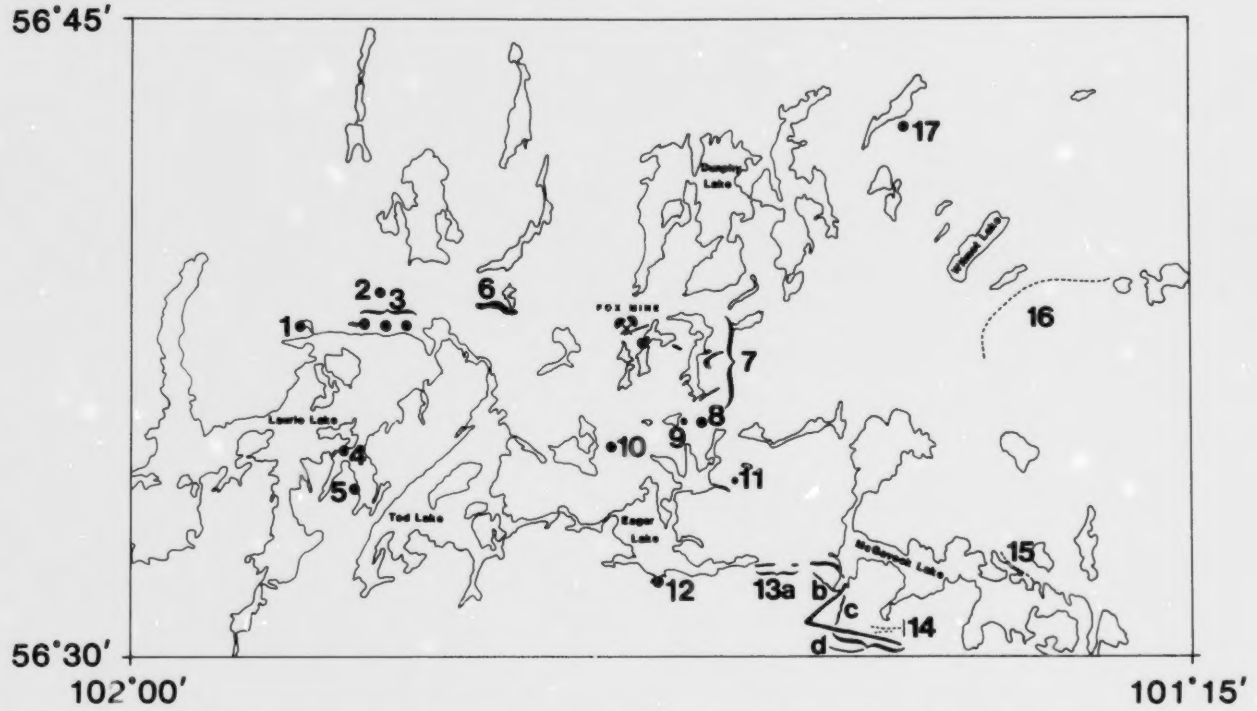

Figure 2: Metamorphosed Alteration Zones of the Laurie Lake Area. Table 1 lists references to works on some of these zones. Zones not previously recognized are briefly described below.

Zone 4: Rock types within the immediate area include; aluminous metasediments, quartzofeldspathic metasediments, mafic to ultramafic metavolcanic rocks, and pillowed mafic metavolcanic rocks. The metamorphosed alteration occurs as: patchy cummingtonite and/or garnet rich regions in amphibolite; regions of cummingtonite-garnet-sulphide and gedrite-garnet-sulphide within pillowed mafic metavolcanic rocks; and sillimanite-rich patches that transect bedding presence of drill holes, cut lines, and trenching.

Zone 5: This zone is approximately 25 m thick and occurs within amphibolites which include; diopside-plagioclase and hornblende-plagioclase banded amphibolite; hornblende-rich amphibolite; and massive to weakly-foliated garnet amphibolite. Alteration is represented by garnet-gedrite-cordierite-, gedrite-garnet-tourmaline, and cummingtonite-plagioclase-quartz-rich rocks.

Zone 8: Stanton (1949) mapped these rocks as "garnet-actinolite-cordierite-quartz-plagioclase gneiss". Other zones similarly mapped by Stanton (1949) are now known to be alteration zones (e.g. New Fox Alteration Zone; Barham, 1987); therefore this locality probably represents an alteration zone.

Zone 9: Small zones of cummingtonite-rich amphibolite.

Zone 10: Previously mapped by Stanton (1949) as "garnet-actinolite-cordierite-quartz-plagioclase gneiss". The writer examined this locality and found gedrite rich rocks with garnet and cordierite. Associated rocks include: amphibolites, garnet-hornblende siltstones, and quartzofeldspathic sediments.

Zone 12: This zone extends at least 20 m inland to the east. North of the zone are mylonitized granitic gneisses and south of it are potassic-calcareous sediments. The zone is approximately 20 m wide. The alteration consists of plagioclase-cummingtonite (± garnet)-, hornblende-garnet-cummingtonite-, and gedrite-rich rocks. A small gossan and some sulphide enclosed in large garnets are present.

Zone 16: This was mapped by Oliver (1952) as a unit containing hornblende, garnet and cordierite. It may represent an alteration zone because some other rocks mapped as such by Oliver have been shown to be alteration zones.

ALTERATION ZONES OF THE LAURIE LAKE AREA

Location #	Name	Reference
(Fig. GSC-17-2)		
1*	Lar	Mustard (1974) Elliott (1984)
2*	Gran	Stewart and Brewar (1984)
3	no name	Mustard (1974)
4*	no name	this study Stewart and Brewar (1984)
5	no name	this study
6*	New Fox	Stanton (1949) Stewart and Brewar (1984) Barham and Froese (1986)
7*	Fox Mine/ Snake Lake region	Stanton (1949) Olson (1984)
8	no name	Stanton (1949)
9	no name	this study
10	no name	Stanton (1949) this study
11	no name	this study
12	no name	this study
13	Eager McGavock	
13a		this study
13b		Stanton (1949) this study
13c		Stanton (1949)
13d		Oliver (1952)
14**		Gilbert et al. (1980)
15**		Gilbert et al. (1980)
16***		Oliver (1952)
17*		Ferreira and Baldwin (1984)

* Sherritt Gordon Mines Ltd. discovered and/or worked on zones 1, 2, 3, 6, 7 and 17.

** Zones 14 and 15 are reported as garnetiferous amphibolite; however, the writer found 13b to be alteration-zone rock and thus 14 and 15 should be examined in the light of this new interpretation.

*** Mapped by Oliver (1952) as garnet-hornblende-cordierite-rocks this unit also may be an alteration zone.

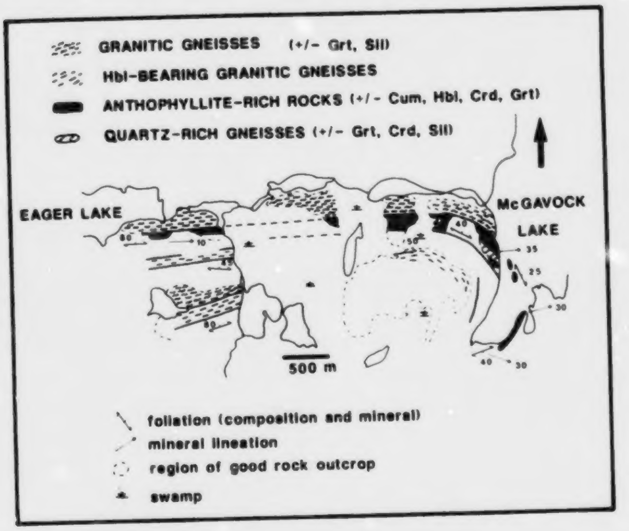
GRANITIC GNEISSES (+/- Grt, Sil)
Hbl-BEARING GRANITIC GNEISSES
ANTHOPHYLLITE-RICH ROCKS (+/- Cum, Hbl, Crd, Grt)
QUARTZ-RICH GNEISSES (+/- Grt, Crd, Sil)
EAGER LAKE
McGAVOCK LAKE
500 m
foliation (composition and mineral)
mineral lineation
region of good rock outcrop
swamp

Figure 3: The Eager-McGavock Lake Alteration Zone. Near southwest McGavock Lake, Stanton (1949) mapped rocks containing garnet, "actinolite", and cordierite (Zone 13b and 13c of Figure 2). Oliver (1952) delineated a zone (13d of Figure 2) of rocks, continuous with those mapped by Stanton, containing "hornblende", garnet, and cordierite. Mapping during this study revealed that these rocks are cordierite-gedrite rocks. Two main types of alteration are present:

1) gedrite-rich zones with rocks containing:

gedrite-garnet-cordierite
gedrite-garnet-cummingtonite
hornblende-cummingtonite-garnet

2) quartz-rich gneisses including different proportions of sillimanite, garnet and cordierite.

This alteration zone may be the largest in the Lynn Lake region. Additional mapping should be carried out to determine the extent of this zone and whether or not massive sulphides are associated with it.

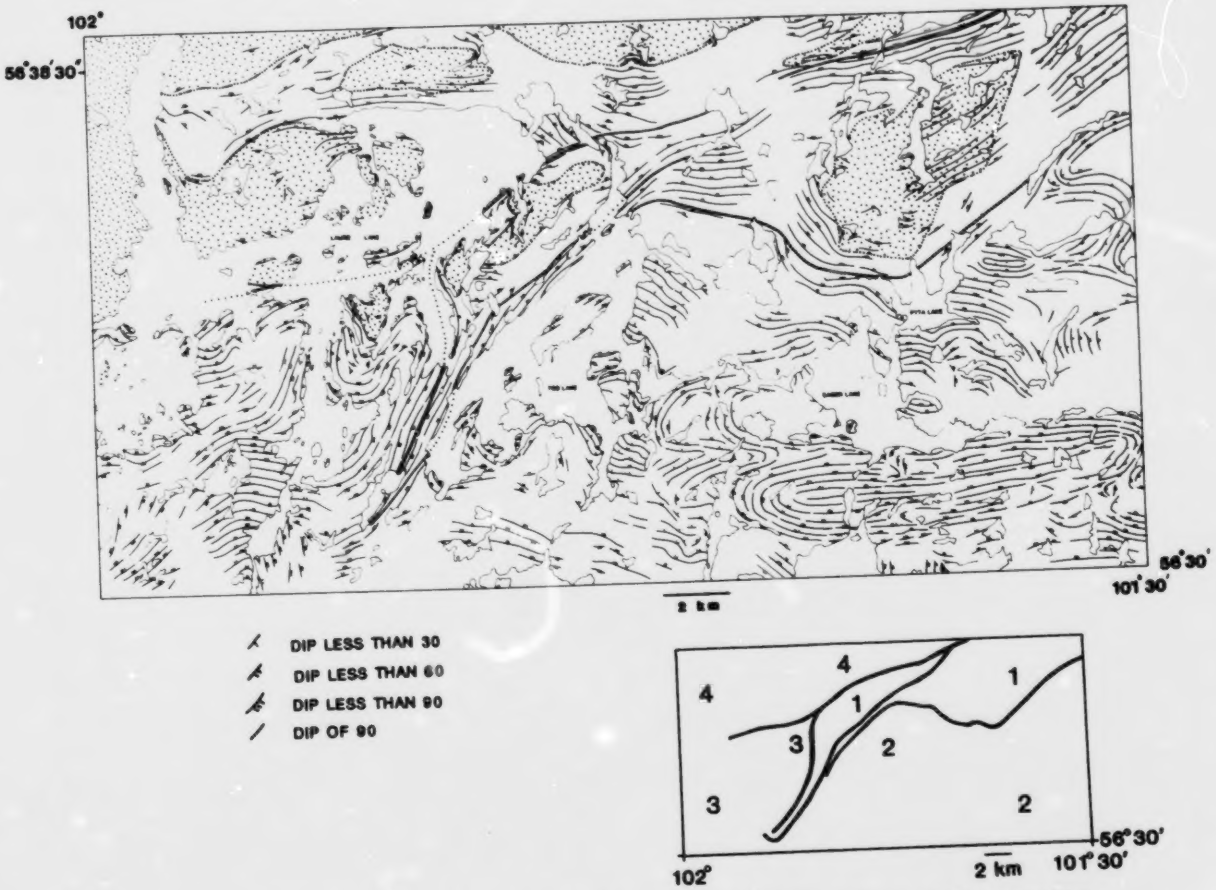
102°
56°38'30'
56°30'
101°30'
2 km
DIP LESS THAN 30
DIP LESS THAN 60
DIP LESS THAN 90
DIP OF 90
4
4
1
1
3
2
3
2
56°30'
102°
2 km
101°30'

Figure 4: Structural domains of the Laurie Lake Area. Small diagram (lower right) identifies the domains. Large diagram is a contoured foliation map of layer-parallel foliation. Thick lines represent faults; unconnected dots represent extrapolation of faults; dotted line represents the metavolcanic belt - metasedimentary belt boundary. Stippled regions represent intrusive rocks.

2) In K-poor aluminous metasediment and metamorphosed alteration zones, staurolite-bearing rocks gave way to garnet-cordierite-sillimanite-bearing rocks

3) In K-poor aluminous metasediments quartz-plagioclase leucosomes appeared and increased in abundance.

Application of linear programming demonstrates that garnet-staurolite-biotite-, garnet-biotite-sillimanite-, and garnet-biotite-sillimanite-cordierite-bearing metasediments can be related by mass balance equations. Therefore, the differing mineral assemblages are due to differing degrees of metamorphism.

Calculated physical conditions of metamorphism (575 to 750°C at ~5-6 kb), the distribution of Fe and Mg between coexisting silicates, and evaluation of an equilibrium involving ferroparagasite, almandine, grunerite, plagioclase, and quartz indicates that the preserved metamorphic gradient is due to variable temperature of metamorphism at uniform pressure.

Interpretation of mineral assemblages and non-equilibrium textures indicates that rocks from the Laurie Lake area followed relatively shallow P-T trajectories (Figure 5). Highly elevated thermal gradients during tectonic loading are believed to be responsible for the determined trajectories.

Consideration of calculated geothermal gradients, P-T calculations, and geochronological data indicates that the high-temperature moderate-pressure conditions of metamorphism could not have been attained without an additional heat supply and/or internal heat generation above the model values and/or a more efficient transfer of heat from lower- to mid-crustal levels (see Gordon, in press). It is postulated that plutons, derived from the lower crust, accelerated the rise in the geothermal gradient at mid- to upper-crustal levels.

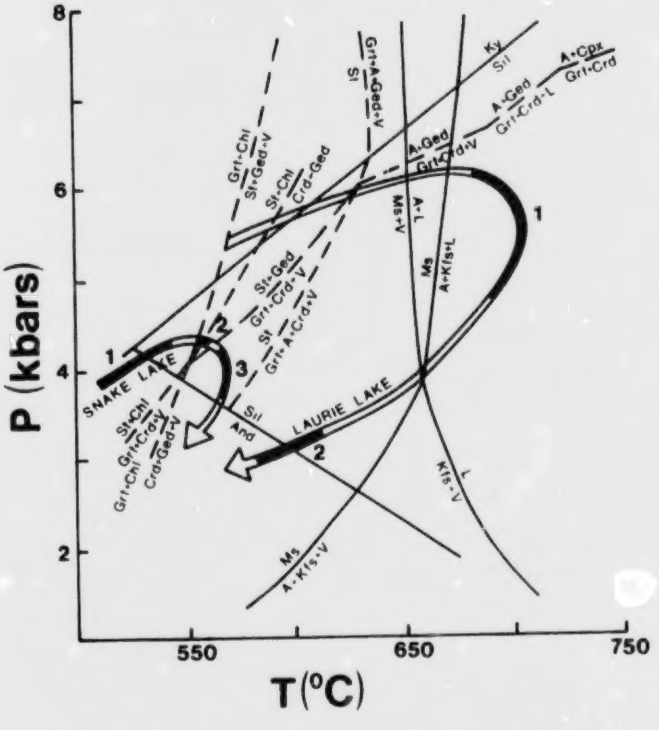

Figure 5: Schematic P-T paths determined for rocks from the northern protion of the Laurie Lake Area (curve labelled "SNAKE LAKE") and the southern portion (curve labelled "LAURIE LAKE") superimposed on petrogenetic grid of Carmichael et al. (1987). Numbers and solid portions of trajectories represent portions of the curves constrained by observations (see Jackson, 1988).

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THE SOUTHERN FLANK OF THE KISSEYNEW GNEISS BELT IN SASKATCHEWAN AND ITS BOUNDARIES WITH THE FLIN FLON VOLCANIC BELT AND HANSON LAKE BLOCK

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Recent 1:50,000 scale re-mapping of the southern flank of the Kisseynew gneiss belt in Saskatchewan (Ashton, 1987, in prep.; Ashton and Wheatley, 1985, 1986; Ashton et al., 1986, 1987,) has elucidated stratigraphic relations. All of the major units of the Flin Flon volcanic belt have been traced continuously into the Kisseynew gneiss belt in the Granite Lake area allowing a broad stratigraphic correlation between the two belts and northward extension of the basic two-fold stratigraphic subdivision (Ashton et al., 1987). The supracrustal succession of the Kisseynew gneiss belt, therefore, includes: 1) the lower 1886 +/-2 Ma (Syme et al., 1987) Amisk Group, consisting of subalkaline, predominantly tholeiitic, mafic to felsic volcanic rocks and derived proximal volcaniclastic rocks and distal graphitic wackes with minor arenites, feldspathic quartzites and mudstones and 2) the unconformably overlying 1832 +/-2 Ma (Gordon et al., 1987) Missi Group of magnetiferous arenites, minor wackes and basal polymictic conglomerates.

Rocks older than the Amisk Group have not been recognized. A suite of unroofed Pre-Missi granitoid plutons with U/Pb zircon dates of about 1890 (Gordon et al., 1987), 1874 (Zwanzig et al., in prep.), 1845 (Syme et al., 1987; Blair, 1988) and 1830-1835 Ma (Gordon et al., 1987; pers. comm., M.E. Bickford, 1989) is likely the source of much of the Missi Group quartzofeldspathic detritus and may include many of the granodiorite-tonalite stocks occurring along the Flin Flon volcanic belt - Kisseynew gneiss belt boundary. Post-Missi intrusive rocks include calc-alkaline granodiorite-tonalites, a number of gabbroic suites and late pegmatitic material of probable metamorphic origin.

Although the continuity of a variety of volcanic and sedimentary Amisk rocks across the Flin Flon volcanic belt - Kisseynew gneiss belt boundary in the west implies stratigraphic correlation, a facies change is also inferred by the transition from interlayered volcanic and sedimentary rocks in the western and southern regions to the dominantly sedimentary terrane of Amisk wackes to the north and east (Ashton et al., 1987). It is likely that structural telescoping has affected the area but the facies change is still recognizeable in the gradation from proximal, thinly layered wackes, mudstones and tuffs, through graphitic and calcic wackes into a distal facies of turbiditic graphitic wackes with minor shallow-water(?) interlayered arenites, feldspathic quartzites and mudstones.

According to this stratigraphic correlation of rocks along the southern flank of the Kisseynew gneiss belt, amphibolites and wackes previously assigned to the Sherridon (Bateman and Harrison, 1946), Nokomis (Robertson, 1953) and Burntwood River (Baldwin et al., 1979) groups and/or metamorphic suites are interpreted as high-grade equivalents of the Amisk Group. The predominantly magnetiferous arenaceous rocks and minor polymictic conglomerates which have previously been classified as parts of the Sherridon Group are considered high-grade equivalents of Missi rocks but others, including those at the type locality (Froese and Goetz, 1981) are regarded as Amisk felsic volcanic and volcaniclastic rocks (Ashton and Froese, 1988).

The sequence of quartz-rich gneisses, calc-silicate rocks, amphibolites and garnet-biotite gneisses at Sherridon also appears at Wildnest Lake in Saskatchewan where it is more clearly the high-grade equivalent of an Amisk succession. The quartz-rich gneisses range in SiO2 content up to 77% at Wildnest Lake and 82% at Sherridon which is consistent with the 68-83% values obtained from Amisk felsic volcanic rocks from the Flin Flon area (pers. comm., E.C. Syme, 1988). Together with their spatial association with Amisk amphibolites and wackes, this has been taken to indicate Amisk felsic volcanic and volcaniclastic precursors. Cummingtonite-garnet rocks are common in the quartz-rich gneisses at both Sherridon and Wildnest Lake and are interpreted as zones of pre-metamorphic hydrothermal alteration. The local presence of sillimanite in the quartz-rich gneisses has also been attributed to alteration and is considered comparable to the widespread occurrence of aluminous minerals in altered felsic volcanic rocks at Snow Lake described by Bailes et al. (1987). The interpretation of the quartz-rich gneisses at Sherridon as a felsic volcanic rather than sedimentary sequence also has the advantage of providing a more satisfactory, volcanogenic model for the massive sulphide deposits, similar to that of Cu-Zn deposits in the Flin Flon - Snow Lake volcanic belt.

A highly variable carbonate content in rocks of a large compositional range suggests that the calc-silicate rocks and impure marbles at Sherridon and Wildnest Lake originated by carbonatization of felsic and mafic volcanic rocks prior to metamorphism.

The metamorphic grade increases from sub-greenschist facies 8 km southeast of Flin Flon (Bailes and Syme, 1987), to greenschist facies in the southeastern part of the area mapped, where the isograds are irregular due to contact effects related to granodiorite-tonalite stocks and late shearing, and to upper amphibolite facies in the far west and north. Closely spaced isograds marking the first appearance of biotite, garnet, staurolite-biotite, sillimanite-biotite and sillimanite-biotite-garnet extend from the Annabel Creek area to Welsh Lake, where they diverge in a southwest direction (Ashton, in prep.). Large metamorphic gradients across individual shear zones were not recognized indicating that the peak of metamorphism followed structural telescoping. This is consistent with the views of Byers and Dahlstrom (1954), who were the first to point out that this part of the boundary was not defined by a system of late faults as suggested by Harrison (1951) and Parslow and Gaskarth (1988). If isograds representing the first appearance of sillimanite-biotite (pers. comm., Zwanzig, 1988) or sillimanite-biotite-garnet (Froese and Moore, 1980) are used to mark the boundary as has been previously suggested by workers in Manitoba, it would extend from the Annabel Creek area in the east, south of Welsh Lake to the Scoop Rapids area of the Sturgeon-Weir River. This would increase the area included in the Kisseynew gneiss belt relative to Byers and Dahlstrom (1954), who placed the boundary further north based on a poorly defined change in metmorphic grade.

The highest grades of metamorphism are exhibited by rocks in the far west and north where some partial melting has occurred although its first appearance is difficult to determine because of other processes including fluid diffusion and injection of granitoid material which result in similar structures.. K-feldspar-sillimanite/kyanite assemblages were not recognized.

Carmichael's (1978) bathozone classification for determining the exposed level of crust was used to indicate a similar northward and westward increase in peak metamorphic pressures to bathozone 5. Relict kyanite-biotite-garnet assemblages in the southern Wildnest - southern Mari Lake area indicate pressures in excess of 5.5 kb (Archibald et al., 1983). Anthophyllite-sillimanite assemblages from southwestern Granite Lake increase the peak pressure estimate to a maximum of at least 5.9 kb (pers. comm., D.M. Carmichael, 1989). The northward gradient likely results from tectonic thickening followed by metamorphism, isostatic uplift and erosion, but the western gradient is attributed to the reverse dip-slip component of displacement along the late, moderately east-dipping Sturgeon-Weir shear zone.

Compilation and correlation of structural data within the Kisseynew gneiss belt, Flin Flon volcanic belt and Sturgeon-Weir shear zone, together with an ongoing structural study of the Amisk-Welsh lakes area (Wilcox, 1989) led to the following working model. The earliest deformation (D1) is inferred in the Flin Flon volcanic belt from back-to-back structural facing directions between Amisk and Missi rocks along unconformable contacts (Bailes et al., 1987). In the Kisseynew gneiss belt, the earliest deformation is represented by isoclinal folds in Amisk wackes and interlayered arenites, feldspathic quartzites and mudstones which produced a strong axial planar foliation. Many of the granitoid plutons and gneissic domes within the Flin Flon and Kisseynew belts yield Pre-Missi, 1890-1830 Ma U/Pb zircon dates, suggesting that D1 deformation began immediately after the iniation of Amisk volcanism at about 1886 +/-2 Ma (Syme et al., 1987) and was continuous into Missi time.

Following a period of uplift, erosion and deposition of the 1832 +/-2 Ma (Gordon et al., 1987) Missi Group, a major compressional event (D2) resulted in isoclinal folding of both Amisk and Missi rocks, with the development of a regional, axial planar foliation and less-pervasive lineation.

Continued tight to isoclinal folding refolded some D2 structures but was generally co-linear, producing large-scale nappes and the generally shallow dips of the Kisseynew terrane. A late-D3 layer-parallel shearing event with accompanying asymmetric minor drag folds and crenulations was responsible for regionally sheared contacts between Amisk and Missi rocks and granitoid stocks. Kinematic indicators along these northwest- to west-striking zones consistently indicate oblique sinistral > reverse displacement which offsets metamorphic isograds in the Flin Flon volcanic belt - Kisseynew gneiss belt transition zone. The 1824 +/-2 Ma Neagle Lake Pluton (Ashton, in prep.) apparently truncates one of these shear zones (the West Channel Fault) on Amisk Lake.

Upright to overturned northeast-plunging D4 folds through Mari, Cotteral and Wormworth Lakes were later tightened by continued deformation represented by the open, upright, gently north-plunging Yaskowich Lake fold. East-plunging cross folds at Philfoster and Schotts Lake and extending eastward from Florence Lake likely formed late in D4 time creating type 2 interference (Ramsay, 1967).

The Embury and Wildnest Lake folds are broad, open, upright D5 structures which transect the Flin Flon volcanic belt - Kisseynew gneiss belt boundary and fold the sinistral D3 shear zones from east- to southeast-striking in the west to south-striking to the south and east.

The moderately east-dipping, ductile Sturgeon-Weir shear zone (D6) represents the western boundary of the Kisseynew gneiss belt and Flin Flon volcanic belt and consists of a wide straight zone, locally containing porphyoclastic granodioritic gneisses. A set of mechanically independent kinematic indicators consistently indicates oblique right lateral-reverse shear, confirming previous suggestions that the Flin Flon volcanic belt and Kisseynew gneiss belt have been thrust over the Hanson Lake Block (MacQuarrie, 1979). Sheared garnetiferous pegmatite from the eastern margin of the Sturgeon-Weir shear zone yields a preliminary 207Pb/206Pb zircon date of 1805 Ma which is interpreted as a maximum age for shearing within the zone.

Northwest- to northeast-striking, apparent-sinistral, brittle faults (D7), including the Ross Lake and Granite Lake faults and late faulting and cataclasis along the Sturgeon-Weir River, postdate all phases of folding and represent the latest phase of regional deformation.

Several new sites of economic interest were located to add to the known Au and massive sulphide occurrences. These include a cordierite-anthophyllite-sillimanite locality on the southwest side of Granite Lake and extensive zones of cummingtonite-garnet rocks in the Wildnest Lake area. Both are interpreted as high-grade equivalents of hydrothermal chloritic alteration zones and further indicate the high-potential for Cu-Zn mineralization in the area. Extensive calc-silicate rocks and impure marbles in the Wildnest Lake area are also attributed to pre-metamorphic alteration.

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Geochronology in the Churchill Province

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This joint project of the Geological Survey of Canada and Manitoba Energy and Mines was designed to 1) establish the absolute timing of regional scale geological events in the Lynn Lake, Rusty Lake, Kisseynew, and Flin Flon belts, and 2) provide controls for local stratigraphic and structural studies. Results are published and in press (see References) and are summarized in Figure 1 and Table 1. The results of this project provide a quantitative reference frame for stratigraphic and tectonic correlation within the Churchill Province in Manitoba. Among the significant findings are identification of subvolcanic intrusive bodies, thought to be heat sources for mineralizing convection cells; confirmation of the time equivalence of the Flin Flon belt and southern flank of the Kisseynew belt, providing a quantitative rationale for stratigraphically oriented exploration programs; and the demonstration that the main regional metamorphic event is probably related to formation of mineralized quartz veins.

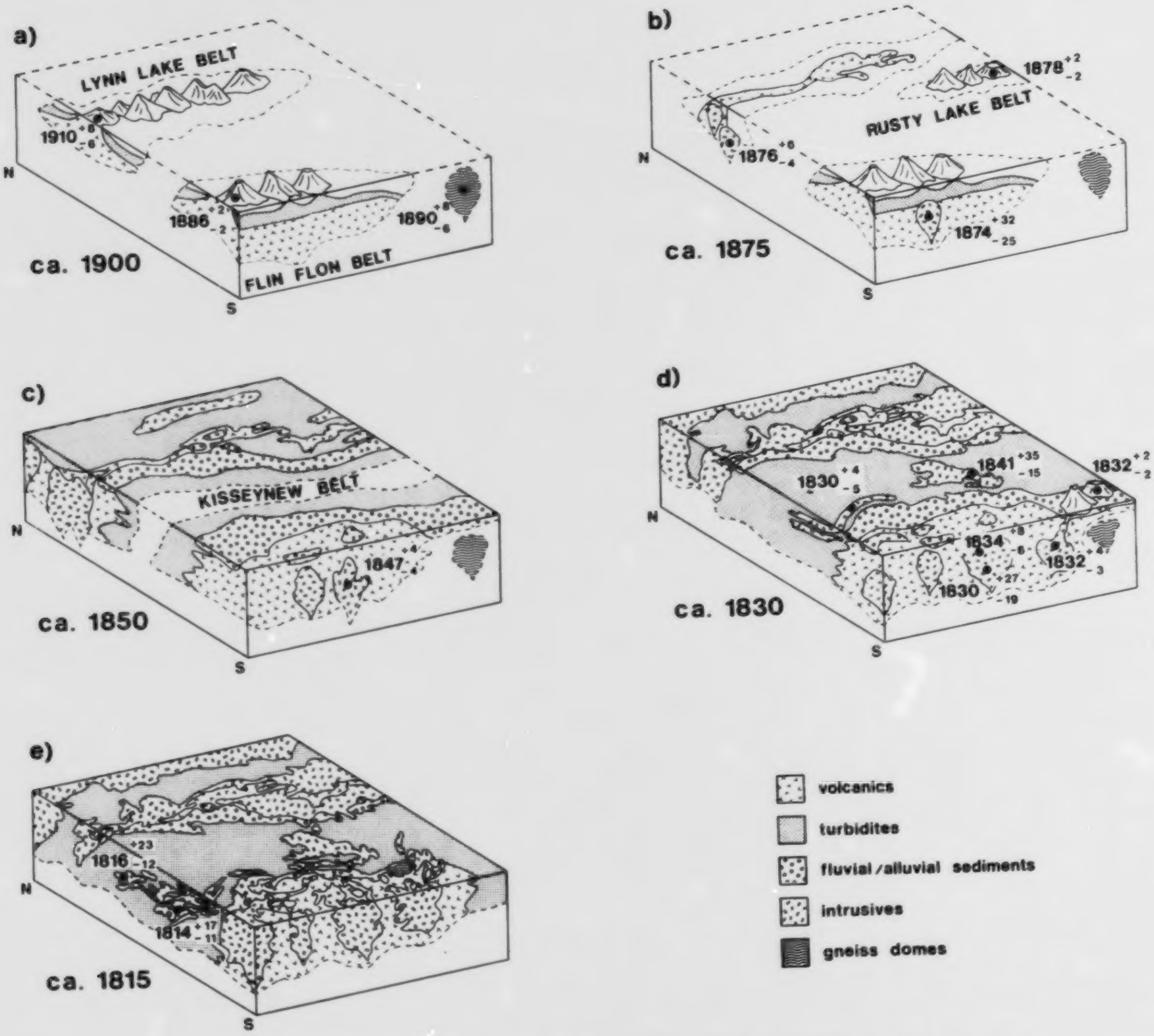
a)
LYNN LAKE BELT
1910 +8 -8
N
1886 +2 -2
1890 +8 -6
ca. 1900
FLIN FLON BELT
S
b)
1878 +2 -2
RUSTY LAKE BELT
N
1876 +6 -4
1874 +32 -25
ca. 1875
S
c)
KISSEYNEW BELT
N
1847 +4 -4
ca. 1850
S
d)
1830 +4 -5
1841 +35 -15
1832 +2 -2
N
1834 +8 -8
1832 +6 -3
1830 +27 -19
ca. 1830
S
e)
1816 +23 -12
N
1814 +17 -11
ca. 1815
S
volcanics
turbidites
fluvial/alluvial sediments
intrusives
gneiss domes

Figure 1. Diagrammatic summary of results of Churchill Province geochronology program as discussed in text.

SUMMARY OF GEOCHRONOLOGY RESULTS FROM THE CHURCHILL PROVINCE.

Unit, Localtiy	U-pb Age(s) (Ma)	Significance	References
		LYNN LAKE BELT	
Lynn Lake rhyolite, Wasekwan Group, Frances Lake	1915 +7/-6, 1910 +15/-10	from oldest sequence	Baldwin et al., 1987
Quartz diorite, pre-Sickle intrustions, Hughes Lake	1876 +8/-7	cuts folded Wasekwan, pre-Sickle	Baldwin et al., 1987
Tonalite, pre-Sickle intrusions, Norrie Lake	1876 +8/-6	cuts folded Wasekwan, pre-Sickle	Baldwin et al., 1987
		RUSTY LAKE BELT	
Rhyolite, Karsakuwigamak block, winter road	1878 +3/-3, 1874 +8/-7	from oldest sequence top of section	Baldwin et al., 1987
		FLIN FLON BELT	
Rhyolite crystal tuff, Amisk Group, Bear Lake fault block	1886 +2/-2	from oldest sequence	Syme et al., 1987; Gordon et al., 1987, in press
Cliff Lake pluton, Cliff Lake	1874 +32/-25	subvolcanic	Gordon et al., 1987, in press
Richard Lake tonalite, Snow Lake	1889 +8/-6	subvolcanic	Bailes et al., 1988
Lynx Lake pluton, Athapapuskow Lake	1847 +4/-4	cuts folded Amisk, faulted	Syme et al., 1987; Gordon et al., 1987, in press
Central plutonic complex, Cormorant Lake	1845 +10/-8	major intrusion	Blair et al., 1988
Ham Lake pluton, File Lake	1830 +27/-19	postdates D1, predates D2 and metamorphism	Gordon et al., 1987, in press
Chickadee rhyolite, Missi Group, Herb Lake	1832 +2/-2	youngest precrustal rocks, predates D1	Gordon et al., 1987, in press
Rex Lake plutonic complex, Wekusko Lake	1832 +4/-3	predates D2	Gordon et al., 1987, in press
Wekusko granite, Highway 392	1834 +8/-6	postdates D2?	Gordon et al., 1987, in press
		KISSEYNEW BELT	
Herblet Lake gneiss dome, Herblet Lake	1890 +8/-6	correlates with Amisk Group	Gordon et al., 1987, in press
Enderbite, File River	1830 +11/-5	oldest intrusions, predates metamorphism	Gordon et al., 1987, in press
Tonalite, Highrock Lake	1841 +35/-15	postdates enderbite, predates granodiorite	Gordon et al., 1987, in press
Granodiorite, Burntwood Lake	1814 +17/-11	anatectic, predates granite	Gordon et al., 1987, in press
Granite, Burntwood Lake	1816 +23/-12	anatectic, peak metamorphism	Gordon et al., 1987, in press

Volcanic rocks in the Lynn Lake and Flin Flon belts were deposited at ca. 1900 Ma (Figure 1a). The Cliff Lake pluton and Richard Lake tonalite are similar in age to the Amisk Group at Flin Flon, suggesting that they were subvolcanic and hence possible heat sources for local hydrothermal systems. The age of orthogneiss in the Herblet Lake gneiss dome supports the interpretation that the southern flank of the Kisseynew gneiss belt is a metamorphosed extension of the Flin Flon belt.

At ca. 1875 Ma (Figure 1b) pre-Sickle granitoid rocks intruded the isoclinally folded Wasekwan Group in the Lynn Lake belt. Rhyolite in the Karsakuwigamak block in the Rusty Lake belt is comparable in age to these intrusions, demonstrating that the two volcanic belts have separate histories. This age is similar to that of intrusive gneisses in the Kisseynew Gneiss Belt (Hunt and Zwanzig, in press), confirming the time equivalence of metavolcanic rocks in the southern flank of the Kisseynew belt with the economically significant Amisk Group.

From ca. 1860-1845 Ma. (Figure 1c) wide-spread plutonism produced the Wathaman-Chipewyan batholith as well as the Lynx Lake pluton on Athapapuskow Lake and the large central plutonic complex in the Cormorant Lake area. Recent GSC work in Saskatchewan (Delaney et al., in press) shows that the uplift and erosion of plutons resulted in deposition of the Ourom Lake arkose near the end of this time period at 1850 +/- 1 Ma.

Sills in the Kisseynew belt were emplaced at 1830 Ma, essentially synchronously with plutonism and Missi Group volcanism in the Snow Lake area (Figure 1d). The Missi Group age is significantly different from that of the Ourom Lake arkose, demonstrating that the various "arkose" sequences in the Churchill province cannot be considered time-equivalent.

The timing of regional metamorphism is established by the ages of anatectic rocks in the central Kisseynew belt at ca. 1815 Ma (Figure 1e). Metamorphism affects the Missi Group and post-dates most folding, constraining the two major periods of deformation observed in the Flin Flon belt to 1830-1815 Ma. This event is thought to result in regional scale fluid migration and formation of mineralized vein systems.

The latest movement on northwest to northeast trending faults juxtaposes rocks of different metamorphic grade, hence must be post- 1815 Ma.

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RESULTS OF STUDIES ON THE GOLD METALLOGENY OF THE FLIN FLON BELT

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INTRODUCTION

The implementation of the Canada-Manitoba Mineral Development agreement provided the Geological Survey of Canada with an opportunity to study the setting of gold mineralization within the Early Proterozoic Flin Flon-Snow Lake Belt. In depth studies were completed on the gold occurrence-rich Wekusko Lake, Snow Lake and Elbow Lake regions of Manitoba, and the Phantom Lake region of Saskatchewan (Figure 1). Preliminary maps have been published for the Elbow Lake and Snow Lake areas (Galley et al, 1987, 1988) and from the Phantom Lake area in Saskatchewan (Galley and Franklin, 1987). Final maps will accompany a Geological Survey of Canada publication of the project results early in 1990.

The Flin Flon Domain is an Early Proterozoic greenstone belt flanked to the north by the Kisseynew Sedimentary Gneiss Domain, and overlain to the south by flat-lying Phanerozoic sedimentary rocks (Figure 1). It is one of a group of lithological domains that form a collage of Early Proterozoic juvenile terranes composing the Reindeer Zone, a segment of the Trans-Hudson Orogen (Hoffman, 1988).

The Flin Flon Domain contains two principal groups of rocks: the Amisk Group is composed of mainly subaqueous volcanic formations, overlain by a thick succession of immature clastic sedimentary rocks. Terrestrial sedimentary and volcanic rocks of the Missi Group unconformably overlie the Amisk Group rocks (Figure 1). Both groups of rocks have been intruded by felsic to mafic synvolcanic intrusions and large syn-kinematic batholiths. Rhyolite from the Amisk Group is dated at 1886 ± 2 Ma, whereas rhyolite from the Missi Group is dated at 1832 ± 2 Ma (Gordon et al, 1988).

Three phases of post-Missi folding have been recognized in the Flin Flon region, and two in the eastern part of the belt. A series of faults transect the belt at an oblique angle, parallel to the Churchill-Superior boundary. They are relatively late in the tectonic history of the region, and may be related to the latest phase of folding. Peak regional metamorphism took place between 1800 and 1820 Ma, and was accompanied by anatectic plutonism and gneiss dome emplacement (Gordon et. al., 1988).

There are over 100 gold occurrences within the Flin Flon Domain, most of which are restricted to areas underlain by supracrustal rocks and associated sills and dykes (Figure 1). The gold occurrences are shear-hosted, epigenetic vein, or disseminated, mesothermal deposits. The exceptions are the Laural and Phantom Lake deposits, which may be associated with gold-rich epithermal systems and high level intrusive complexes (Galley and Franklin, 1987, this volume).

The principal results of this study are: a) the recognition that groups of gold occurrences are spatially related to regional-scale fault structures, b) the alteration associated with gold mineralization post-dates peak regional metamorphism, and c) a maximum age for gold deposition is similar to that obtained for regional peak metamorphism.

STRUCTURE

Wekusko Lake Gold Occurrences

In the Wekusko Lake region there are two groups of gold occurrences hosted by the Herb Lake Syncline, one of a series of north-northeast trending folds that deform early isoclinal folds across the Snow Lake-Wekusko Lake region (Figure 2). The occurrences are aligned along a series of shear zones that are subparallel to the axis of the syncline (Figure 2). Gold occurrences along the northwest limb of the fold typically consist of single, shear-hosted quartz veins up to one metre wide and up to 500 metres long. These veins are commonly present where the shears intersect either the quartz-feldspar or biotite porphyry stocks that intrude the Missi Group sedimentary and volcanic strata. The shear zones hosting the gold-bearing veins can be traced intermittently for over 1500 metres.

The shear-hosted vein occurrences along the axis of the fold are within a sequence of basaltic andesite and basalt, and are more strongly deformed than their northwest limb counterparts, with strong boundinage of individual veins. Increased deformation is likely due to the relative weakness of the basalt host-rocks under stress in comparison to the more competent felsic stocks. Individual shear zones can be intermittently traced for over 1700 metres, containing up to six individual occurrences. The shears containing the gold occurrences are difficult exploration targets in that they are rarely over five metres wide.

Structural measurements taken during this study on the various auriferous shear zones indicate that the majority of mineral lineations, fragment elongations and slickensides plunge steeply northeast on the plane of the shears. At the

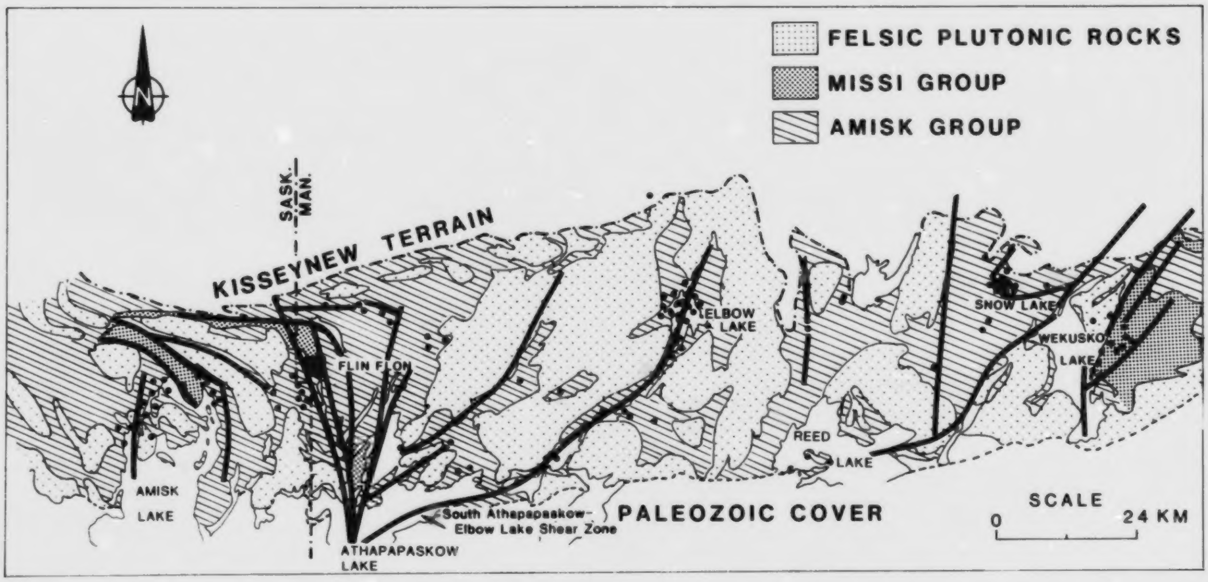


Figure 1. Geology of the Flin Flon Belt emphasizing the relationship between major faults (solid lines) and significant gold occurrences (compiled from Byers and Dahlstrom, 1954; Richardson and Ostry, 1986; Bailes and Syme, 1987; Bailes, 1987 and Syme, 1988)

Rex-Laguna, the shear zone hosting the main vein crosses several monzodiorite dykes, rotating them dextrally. Extensional veins at right angles to the main vein dip shallowly to the southwest, and are buckled. The two gold zones at the Rex Laguna Mine plunge parallel to the lineations (Stockwell, 1937), whereas the four zones defined at the Ferro Mine plunge steeply southwest (D. Zielhke, pers, comm.).

The auriferous vein systems were formed within reverse, north-northeast striking, dip-slip faults in which there was a component of dextral displacement. The strong buckling of extensional veins suggests that some shortening took place across the fault zone. These faults not only are subparallel to the axis of the Herb Lake Syncline, but are also parallel to a series of regional-scale, dextral faults that truncate folds related to the syncline, usually along their anticlinal axes. These include the Stuart Lake, Niblock Lake and Watts River Faults (Figure 2). Several of these faults offset the regional metamorphic isograds (Figure 2). This post-peak metamorphic displacement is compatible with similar overprinting textures observed in the smaller, auriferous faults. The close relationship of the reverse faults to folding is compatible with synchronous formation during a period of regional compression.

Snow Lake Gold Occurrences

All of the major gold occurrences in the Snow Lake area (with the exception of the Squall Lake deposit) lie within a block of Amisk Group volcanic rock that is bordered by the McLeod Road Fault and the Birch Lake Fault. The gold occurrences within this lithological domain are hosted by a number of shears and faults, with the largest deposits within 500 metres of the surface expression of the McLeod Road Fault. The McLeod Road and Birch Lake faults truncate isoclinal folds that deform the volcanic stratigraphy. Both the early folds and faults have been subsequently folded by a north-northeast trending structure known as the Threehouse Syncline. A prominent regional lineation parallels the hinge of this fold.

The gold occurrences consist of quartz-albite-carbonate breccia veins that contain angular fragments of altered and mineralized wallrock. The smaller showings are typified by a single vein up to one metre wide, and larger deposits, such as the Nor-Acme, by breccia-vein systems up to 30 metres wide. Auriferous shoots within these veins plunge moderately northeast, subparallel to the regional lineation.

The larger deposits occur where at an inflection along the strike of the host fault, coinciding with the intersection of the fault with the nose of an early, isoclinal fold. The Nor-Acme deposit, which is the largest in the area, is further localized at the fold nose by a bedding contact between dacite and basalt. The exception to the vein

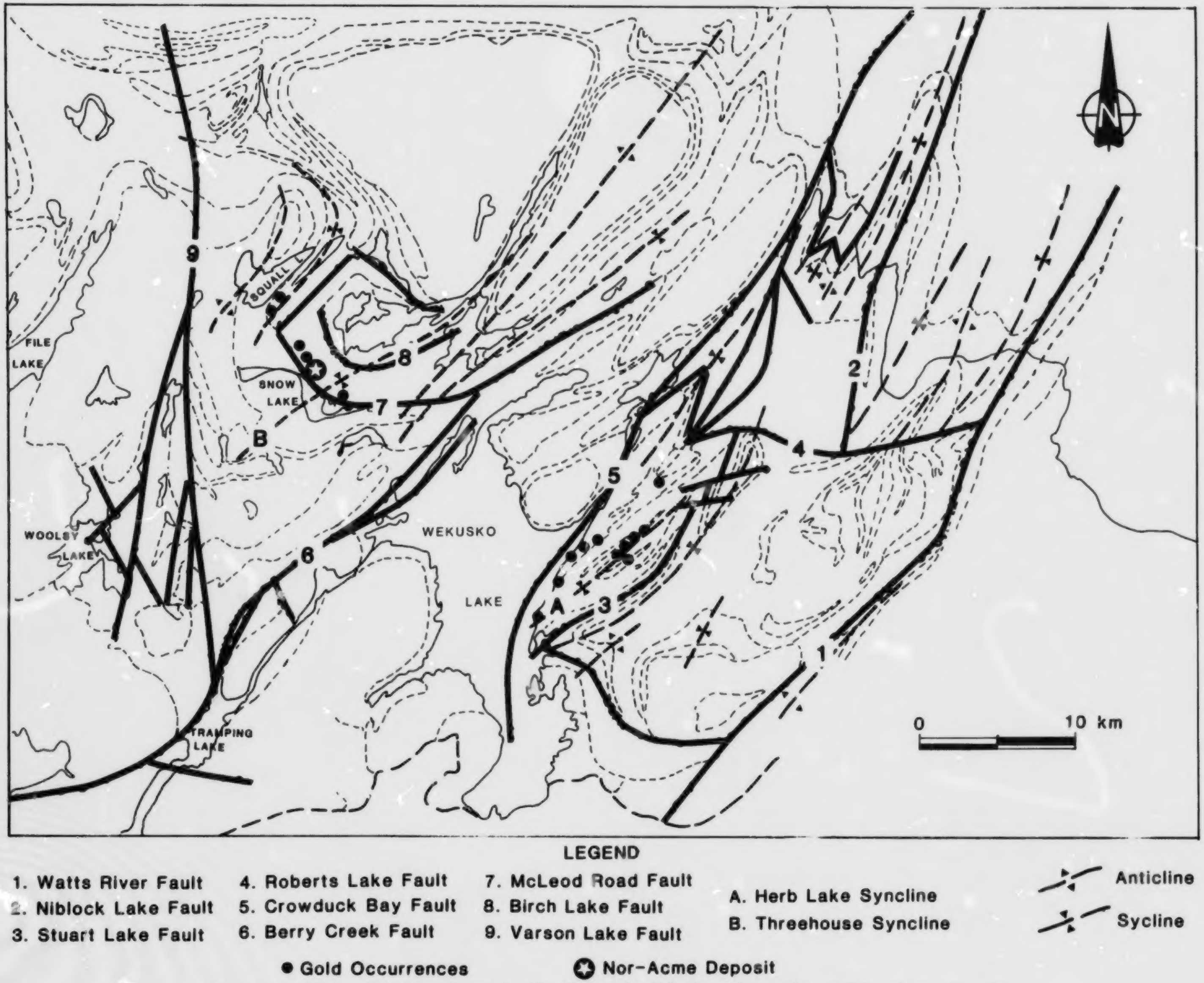

9
SQUALL
FILE LAKE
SNOW LAKE
8
7
B
WOOLSY LAKE
6
WEKUSKO
LAKE
TRAMPING LAKE
5
A
3
4
2
1
0
10 km
N
LEGEND
1. Watts River Fault
2. Niblock Lake Fault
3. Stuart Lake Fault
4. Roberts Lake Fault
5. Crowduck Bay Fault
6. Berry Creek Fault
7. McLeod Road Fault
8. Birch Lake Fault
9. Varson Lake Fault
A. Herb Lake Syncline
B. Threehouse Syncline
Anticline
Sycline
● Gold Occurrences
Nor-Acme Deposit

Figure 2. Major late structures in the Snow Lake-Wekusko Lake region and location of major gold occurrences in the two study areas

breccia-type occurrence is the Bounter, where gold mineralization is disseminated within strongly altered wallrocks in an anastomosed shear zone; there are few veins present. The principal difference between the Bounter and other major deposits is that the former occurs at the intersection of the shear zone and the edge of a gabbro and not at a major inflection point along the shear. Many of the smaller vein occurrences are also localized where a fault forms the boundary between rocks of differing competency.

The auriferous faults are typified by a deflection of the regional foliation across the fault zone, indicating a component of sinistral offset. Mineral lineations plunge moderately to the northeast, whereas extensional veins branching from the main breccia veins are strongly buckled. These fabrics imply the latest movement was oblique reverse, with a component of sinistral displacement. Kinematic indicators along the McLeod Road and Birch Lake faults also infer reverse motion. A carbonate-rich, retrograde mineral assemblage is present within both the domain-bounding and mineralized faults. All of this evidence indicates that the faults were activated during a period of sub-horizontal shortening, which occurred after peak metamorphism. The faults may have either formed, or been reactivated, during their deformation by the Threehouse Syncline (Figure 2).

In summary, gold mineralization in the Snow Lake-Wekusko Lake region can be related to a series of dominantly dip-slip, reverse motion faults that are miniature versions of regional scale faults that have been either reactivated, or formed, during a period of late folding.

Elbow Lake Gold Occurrences

The structural history of the Elbow Lake region is not fully understood; results from this study infer that there are at least three generations of folds, the first represented by isoclinal folds whose axial traces curve southeast to west. A second generation refolds the earlier structures along north-northeast trending axes. The two generations of folds have been affected by the emplacement of syn-kinematic batholiths.

The folded volcanic sequence was subsequently deformed by several large shear zones that cross-cut the regional fabric at a high angle, and control the distribution of the 36 recorded gold occurrences. The Elbow Lake Shear Zone (ELSZ) is up to 1500 metres wide, and strikes 020° up the middle of Elbow Lake (Figure 3). Associated with the ELSZ are conjugate sets of sinistral northwest and dextral northeast striking shears and faults that extend several kilometres from the ELSZ. The Long Creek Fault Zone (LCFZ) is parallel to the ELSZ to the west, and is up to 1200 metres wide (Figure 3), whereas the Claw Bay Shear Zone (CBSZ) curves into the ELSZ from the east and may represent one of the larger, sinistral northwest striking conjugate shears.

The reorientation of sills into the plane of the main shear zone, and the steep stretch lineation associated with the tectonites all suggest that movement along the ELSZ is reverse dip-slip, with a dextral component. Retrograde mineral assemblages within the fault zone overprint the peak metamorphic assemblage. The presence of a generally higher grade metamorphic assemblage on the eastern side of the ELSZ supports kinematic evidence for reverse movement along this lineament post-dating peak regional metamorphism.

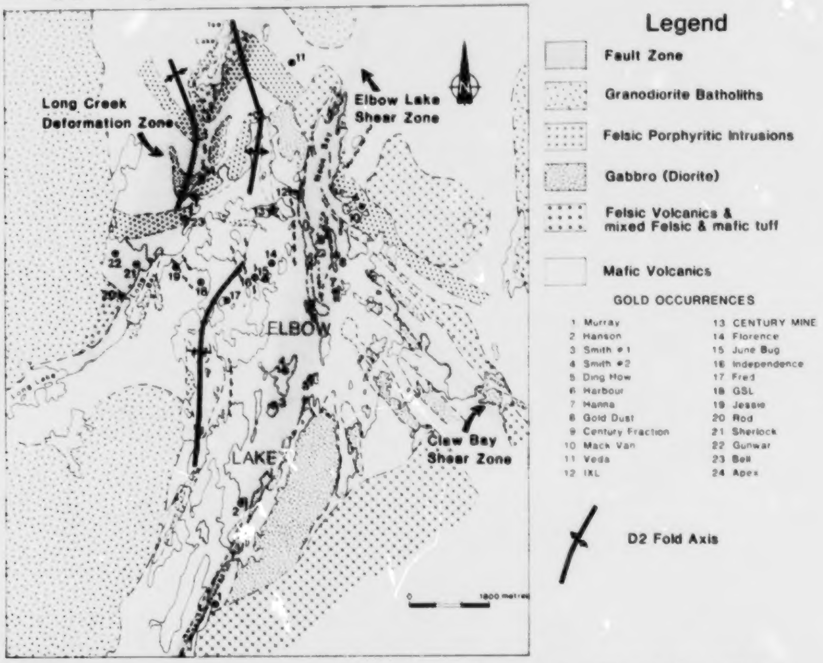

Long Creek Deformation Zone
Elbow Lake Shear Zone
Claw Bay Shear Zone
ELBOW
LAKE
N
0
1000 metres
Legend
Fault Zone
Granodiorite Batholiths
Felsic Porphyritic Intrusions
Gabbro (Diorite)
Felsic Volcanics & mixed Felsic & mafic tuff
Mafic Volcanics
GOLD OCCURRENCES
1 Murray
2 Hanson
3 Smith #1
4 Smith #2
5 Ding How
6 Harbour
7 Hanna
8 Gold Dust
9 Century Fraction
10 Mack Van
11 Veda
12 IXL
13 CENTURY MINE
14 Florence
15 June Bug
16 Independence
17 Fred
18 GSL
19 Jessie
20 Rod
21 Sherlock
22 Gunwar
23 Bell
24 Apex
D2 Fold Axis

Figure 3. General geology and gold occurrences in the Elbow Lake region.

Gold mineralization is hosted by epigenetic, sulphide-bearing, quartz-carbonate-albite veins contained within these late shear zones. Eleven of these occurrences are hosted by felsic dykes, nine within, or along the margins of mafic intrusions, eight in ferruginous sedimentary rocks, five within mafic tectonites and three within felsic tectonites. The variety of rock types hosting gold mineralization within the shear zones shows that there is no primary relationship between lithology and gold content. With the exception of the mafic tectonite-hosted occurrences, the host lithologies to the gold mineralization are more competent than the surrounding rock, so that with the development of the shear zones, these host rocks reacted to deformation in a more brittle fashion, providing an open space for auriferous vein formation.

Airborne magnetometer surveys indicate that the ELSZ extends down through the Cranberry Lakes to Athapapaskow Lake, where Syme (1988) has identified the structure as the South Athapapuskow Shear Zone (Figure 1). Gold occurrences are recorded along the 35 kilometre strike length of this lineament, suggesting that the fault system has a major regional control over gold deposition.

ALTERATION AND MINERALIZATION

Carbonate-rich alteration mineral assemblages associated with gold mineralization overprints the peak regional metamorphic assemblage in the three areas studied. The width of alteration zones varies with the size of the host fault, frequency and spacing of faults, and the composition of the host rocks. In the Wekusko Lake area, visible alteration is restricted to within one to two metres of the auriferous veins. At the Nor-Acme deposit in Snow Lake, alteration is discernible for up to 100 metres from the vein system, with associated veining at right angles to the fault up to 400 metres away. In the Elbow Lake region, the altered shears and faults are so numerous that the carbonate alteration is a principal characteristic of the area.

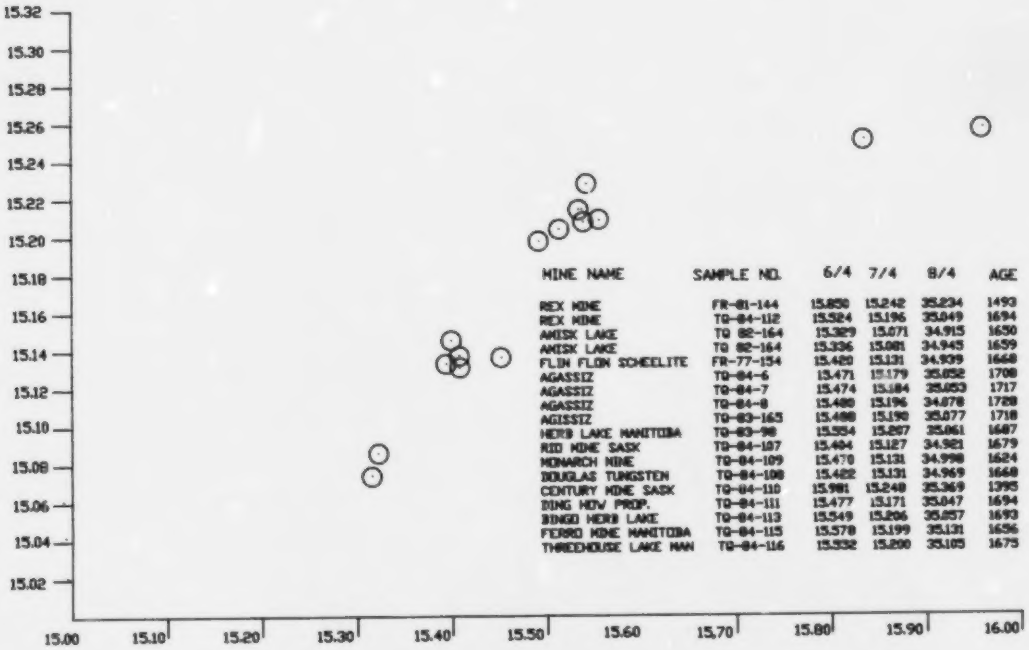
The assemblage quartz-iron carbonate-albite-sericite is always present within, or along the margins of the auriferous veins. The presence of additional minerals in the alteration zone is dependent on host rock lithology and intensity of alteration. Within amphibolite-grade mafic volcanic rocks, metamorphic hornblende was progressively altered towards the gold zone to actinolite, biotite, and chlorite. There is a progressive alteration of metamorphic titanomagnetite to sphene, ilmenite, and ultimately rutile, whereas metamorphic andesine is altered to oligoclase and then albite. These mineral changes are associated with a change in the carbonate species from calcite through ferroan-dolomite to ankerite, with ferroan-dolomite being the most abundant. Tourmaline and scheelite are also common in to many occurrences. The variation in the alteration assemblage toward the veins defines a series of alteration zones centered about the auriferous part of the fault or shear.

Pyrite and arsenopyrite are the principal sulphide minerals associated with gold mineralization, with the sulphides usually present in concentrations of less than 5%. Arsenopyrite-dominated mineralization is restricted to felsic intrusive host rocks in the Wekusko Lake and Elbow Lake areas, but in Snow Lake all of the occurrences are arsenopyrite-rich, with most of them hosted by mafic volcanic and intrusive rocks. Where arsenopyrite is the principal sulphide mineral, it is present as very fine-grained needles that are commonly deformed. Coarser, blocky arsenopyrite crystals indicate the presence of elevated, but not highly anomalous gold values. Small amounts of chalcopyrite, sphalerite and galena are common, with chalcopyrite more common within mafic-hosted deposits. Pyrrhotite is recorded at several occurrences, while a change from pyrite to pyrrhotite with increasing depth has been reported in deposits with extensive mine workings.

LEAD ISOTOPE DATA

These analyses were obtained on galena samples in order to examine genetic and age inter-relationships between deposits and districts. The data (Figure 4) form a distinct linear trend. Deposits within single districts are quite uniform in composition, indicating local homogeniety of the mineralizaing fluids. The closely similar compositions of galena from the Wekusko and Snow lakes areas suggest a genetic link. The points cluster at a higher 207Pb/204Pb than those further west at Elbow Lake (Ding How), Cranberry Lake (Gurney Mine), Lake Athapapaskow (Billy Boy), Flin Flon (Rio, Douglas, Phantom Lake) and Amisk Lake (Monarch, West Amisk). Only the samples from the Century Mine (Elbow Lake) and one sample from the Rex-Laguna are more radiogenic.

The linear distribution of data may be an isochron (M = 0.469 +/- 0.02), indicating that most of the gold deposits formed at about the same time. Alternatively, this may be a binary mixing line, and have no age significance. Using the Stacey and Kramers (1976) model system, the ages range from 1624 Ma to 1728 Ma (av=1683 Ma). Gordon et al. (1988) used the U/Pb ages from various plutons in the Flin Flon belt and Kisseynew Sedimentary Gneiss Domain to establish that the peak of regional metamorphism was between 1800 Ma and 1820 Ma. However, K/Ar age determinations for the eastern part of the Churchill Province (Lowdon et al., 1963; Wanless et al., 1964, 1974) are much younger, and similar to the lead isotope ages. The fact that the gold-associated alteration mineral assemblages overprint the peak metamorphic assemblage implies that 1820 Ma would be a maximum age for gold deposition within these epigenetic systems, and that the actual age may be closer to that established by closure of the Argon system. A major thermal event may have terminated about that time, and gold deposits were thus formed very late in the tectonic history of the region.



MINE NAME	SAMPLE NO.	6/4	7/4	8/4	AGE
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BINGO HERB LAKE	TQ-84-113	15.549	15.206	35.057	1693
FERRO MINE MANITOBA	TQ-84-115	15.578	15.199	35.131	1656
THREEHOUSE LAKE MAN	TQ-84-116	15.532	15.200	35.105	1675

Figure 4. Lead isotope data obtained from gold occurrences from across the Flin Flon belt

EXPLORATION GUIDELINES

Several guidelines are useful in exploring for gold in the Flin Flon Belt:

a) Gold occurrences are associated with late fault systems that transect the regional fabric of the belt at a high angle. The mineral assemblages within the fault zones overprint the peak metamorphic assemblages in the surrounding rocks.

b) Areas along these fault systems most likely to contain gold mineralization are where there is a sudden change in the orientation of the faults or where they cross highly competent rock units at a high angle to the lithologic contact.

c) It is commonly faults and shears secondary to the regional fault that are auriferous. These smaller structures are usually within the hangingwall of the larger fault, and may parallel the structure, or strike at an acute angle to it.

d) Carbonate-rich alteration zones that accompany gold mineralization are useful guides in narrowing the target area. These zones are usually larger than the accompanying auriferous vein system. The use of a carbonate stain (which may be carried about in a plastic container and sprayed on outcrop) is very useful in identifying iron carbonate species in hand specimen or in drill core. The appearance and disappearance of the other indicator minerals described above can mostly be observed in hand specimen.

e) Following the identification of an auriferous zone, a few careful structural measurements within the shear and the surrounding wallrocks will allow for the determination of the plunge of the gold zone. Most of the gold zones examined were contained within dip-slip faults with some component of oblique displacement that was identified by lineation measurements. Within the dip-slip faults, gold zones commonly parallel the direction of movement on the fault plane. A strong regional lineation also appears to have a control on the orientation of the gold zones.

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SETTING OF GOLD IN THE PHANTOM LAKE REGION, SASKATCHEWAN

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Mineral Resources Division
Geological Survey of Canada

INTRODUCTION

The study of gold mineralization in the Phantom Lake region of Saskatchewan was part of a larger project on the gold metallogeny of the Flin Flon Belt, completed by the Geological Survey of Canada under the 1984-89 Saskatchewan-Manitoba Mineral Development Agreements (see Galley et al, this volume). There are three past-producing gold mines in the Phantom Lake region (Figure 1). The gold occurrences are spatially associated with a relatively undeformed, K-spar porphyritic granite (Phantom Lake Granite) that intruded a series of more mafic igneous rocks (Boot Lake intrusion) (Galley et al, 1985). The granite and surrounding intrusive and volcanic rocks contain occurrences of copper, tungsten, molybdenum, gold and silver that are associated with extensive zones of alteration similar to those associated with high-level porphyry systems (Sutherland-Brown,1976; Henley and McNabb,1978). Wallster (1979) hypothesized that copper mineralization within the nearby Boot Lake granodiorite was porphyry-related.

A project was initiated to determine: a) the relationship of precious metal mineralization to the granite porphyry, b) the controls on the deposition of gold, and c) the relationship between gold mineralization in the Phantom Lake area to other gold occurrences in the Early Proterozoic Flin Flon Belt.

REGIONAL GEOLOGY

The Phantom Lake region is located 5 kilometres south of Flin Flon, within the Early Proterozoic Flin Flon Domain, a 200 kilometre-long remnant of a dominantly subaqueous island arc complex, that grades northward into the Kisseynew Sedimentary Gneiss Domain, and is overlain to the south by flat-lying Paleozoic limestone and dolostone. The domain is composed of dominantly subaqueous volcanic rocks of the Amisk Group, that are unconformably overlain by terrestrial clastic sedimentary (and minor volcanic) strata of the Missi Group. Both rock groups are intruded by both synvolcanic intrusions and several ages of synkinematic plutons.

LOCAL GEOLOGY

The Phantom Lake study area is within the Flin Flon Block (Bailes and Syme, 1986), a structural domain dominated by a homoclinal sequence of southwesterly facing mafic volcanic rocks of the Amisk Group. Thin units of rhyolite flow and breccia occur within the basalt stratigraphy, which is overlain by felsic to intermediate volcaniclastic units. Synvolcanic intrusions include gabbro and diorite sills.

The volcanic rocks are bounded to the west and south by the early- synkinematic Reynard Lake and Kaminus plutons (Figure 1), and late-synkinematic intrusions including the Boundary suite and the Boot Lake-Phantom Lake intrusive complex (PLIC) (Galley and Franklin, 1987) (Figure 1). The metamorphic grade in the Flin Flon Block is lower greenschist (Bailes and Syme, 1987).

The region has undergone three phases of post-Missi folding, followed by a period of regional-scale, brittle-ductile faulting (Wilcox, 1989). The late faulting is represented by an extensive system of northerly trending faults. These faults divide the Flin Flon region into a number of distinct lithological domains (Bailes and Syme, 1987; Syme, 1988). The fault system is complex, but can be divided into north-northwest (NNW) and northeast (NE) striking sets. The Phantom Lake region is bounded by the NNW set, which includes the domain-bounding Cliff Lake and Ross Lake Faults (Figure 1). The motion along these steeply east-dipping faults was dominantly oblique-sinistral, with steeply southeast-plunging lineations indicating reverse motion (Stauffer and Mukherjee, 1977).

The Boundary suite and PLIC intrusions post-date the folding events. The Boundary suite was emplaced along the Cliff Lake-Ross Lake fault system, with the early intrusive phases containing a fault-parallel foliation. The younger phases of the suite are massive, suggesting emplacement along

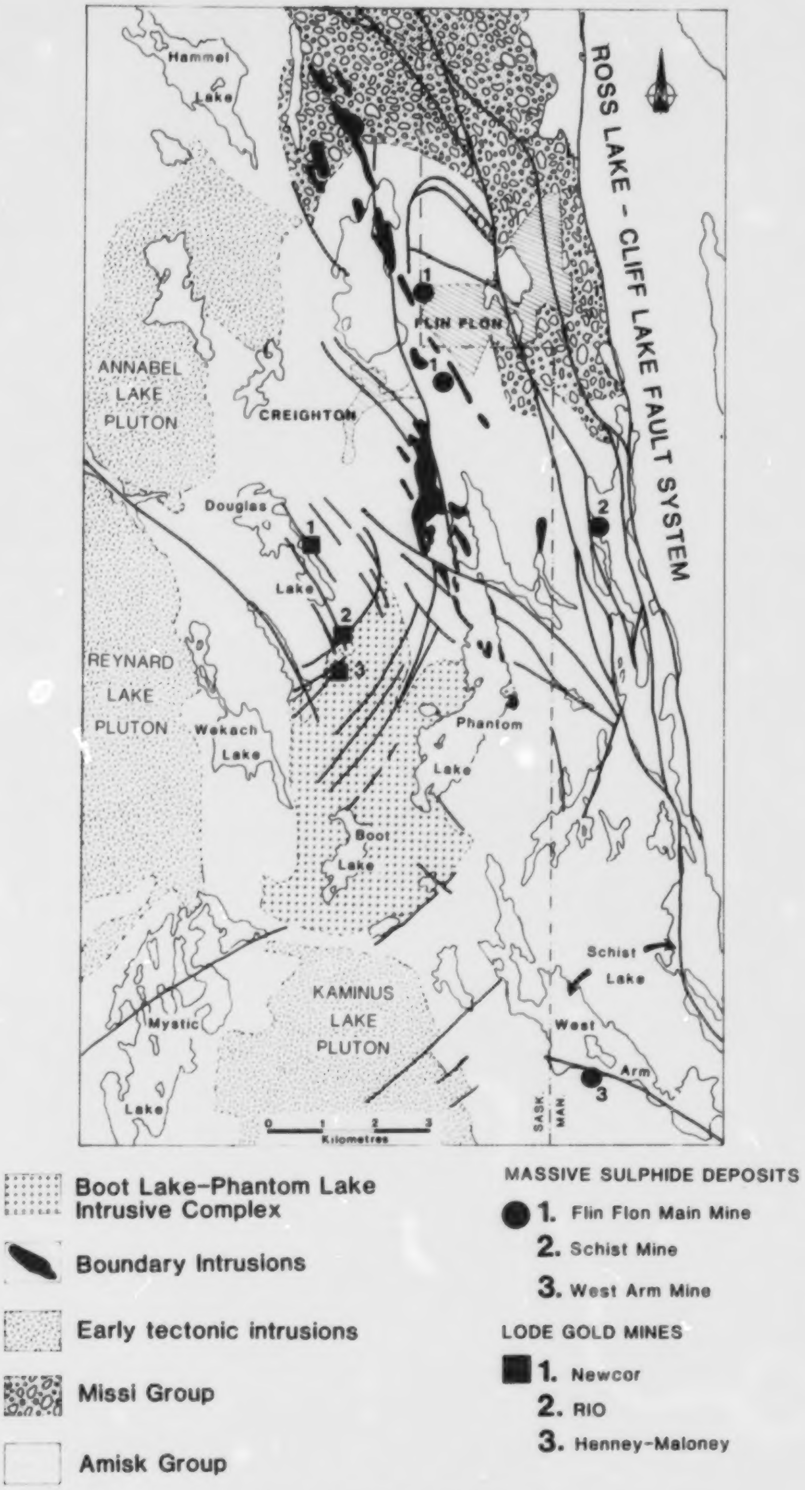

Hammel Lake
ROSS LAKE - CLIFF LAKE FAULT SYSTEM
1
FLIN FLON
1
ANNABEL LAKE PLUTON
CREIGHTON
Douglas
1
Lake
2
2
3
REYNARD LAKE PLUTON
Wekach Lake
Phantom
Lake
Boot Lake
Schist
Lake
KAMINUS LAKE PLUTON
Mystic
Lake
West
Arm
3
SASK.
MAN.
0 1 2 3
Kilometres
Boot Lake–Phantom Lake Intrusive Complex
Boundary Intrusions
Early tectonic intrusions
Missi Group
Amisk Group
MASSIVE SULPHIDE DEPOSITS
1. Flin Flon Main Mine
2. Schist Mine
3. West Arm Mine
LODE GOLD MINES
1. Newcor
2. RIO
3. Henney-Maloney

Figure 1. General geology and major mineral deposits in the Flin Flon-Phantom Lake region

the faults after cessation of movement (Syme and Forrester, 1980). This study has confirmed that the PLIC crosscuts the younger phases of the Boundary suite.

STRUCTURE

As part of this study, the orientations of structural features associated with the PLIC were systematically recorded (Figure 2). These data show that the PLIC is deformed by a number of north-northeast (NNE) and east-southeast (ESE) striking faults common along the west margin of the Cliff Lake-Ross Lake fault system (Figure a-d). This fault system was active both during and after the emplacement of the intrusive complex, as indicated by the preferred alignment of the dykes associated with the complex (Figure e-h), and the faults cross-cutting the PLIC.

The set of NNE and ESE faults are brittle-ductile, marked by a rapid increase in the density of fractures parallel to the fault line, and by the development of a foliation oblique to the fault. The C-S fabric (Berthe et. al., 1979) indicates dextral displacement along the NNE faults and shears, and sinistral displacement along the ESE set (Figure 2b-c). Along the fracture planes, slickensides plunge shallowly (10 to 15°) along both fault sets indicating predominantly strike-slip displacements. Kink-folds deform the shear foliation and plunge steeply sub-perpendicular to the slickensides (Figure 3). The NNE and ESE faults offset one another, indicating that they are coeval.

METAMORPHISM

Primary amphiboles within the Boot Lake-Phantom Lake complex have been variably altered to chlorite and epidote. Biotite is altered to chlorite and plagioclase to sericite. Coronas within the Phase 2 syenite contain remnant clinopyroxene, and prehnite is present in the Phase 1 anorthositic gabbro, indicating that parts of the complex has undergone sub-greenschist grade metamorphism. The volcanic rocks adjacent the intrusive complex are hornfelsed, with the contact metamorphic aureole up to 80 metres wide, thus suggesting high level emplacement into relatively cold, dry country rock.

BOOT LAKE-PHANTOM LAKE INTRUSIVE COMPLEX

With the view that the Boot Lake granodiorite and the Phantom Lake granite, which were previously mapped as pre- and synkinematic respectively, represented a single, multi-phase intrusion, careful attention was taken with respect to the internal zonation, textures and contacts of the igneous rocks. It was concluded that these two bodies are part of a single intrusive complex in which there are five phases (Figure 4). The oldest phase (Phase 1) consists of hornblende diorite, quartz hornblende diorite, anorthositic hornblende gabbro, hornblende gabbro and hornblendite. This was intruded in succession by biotite-hornblende quartz monzodiorite with minor syenite (Phase 2), tonalite (Phase 3), plagioclase porphyritic granodiorite (Phase 4) and a microcline porphyritic monzogranite (Phase 5). The complex is composed of calc-alkaline rocks, and appears to have been formed through the differentiation of an I-type source magma. Unlike calc-alkaline intrusions typical of mature continental island domains, the complex shows strong REE differentiation (Y = 8-81, La = 14-62, Ce = 27-140, Nd = 13-80, Sm = 2-15) (Nurmi and Haapala, 1986).

ALTERATION AND MINERALIZATION

Three types of alteration and mineralization are spatially associated with the PLIC. All three are carbonate-rich and are controlled by fractures, shears and faults. The most extensive alteration type is the hematite-quartz-ferrodolomite-epidote alteration, which is controlled by sets of planar fractures and quartz-filled joints. The alteration is characterized by intense bleaching of the wallrocks within the mafic phases of the intrusion, and by hematite-staining within the granodiorite and monzogranite. This propylitic alteration is concentrated at the margins of the porphyritic monzogranite and associated dykes, suggesting that the alteration is related to the emplacement of the Phase 5 stock. Quartz-fluorite, quartz-molybdenite and quartz-microcline-chalcopyrite breccia veins are spatially associated with this propylitic alteration.

Sericite-quartz-ferrodolomite-pyrite alteration is restricted to zones of shearing and fracturing within the Phase 5 porphyritic monzogranite and within the Phase 3 tonalite where it is transected by the Dion Lake Fault Zone (Figure 4). These alteration zones have been traced for over 100 metres in length and up to 60 metres wide, typically centered about a series of parallel shears and fractures.. These zones overprint zones of propylitic alteration. In the monzogranite the sericite-quartz-ferrodolomite-pyrite alteration contains anomalous concentrations of silver, gold and tungsten. Within the Phase 3 tonalite, the alteration zones contain irregular veinlets of chalcopyrite and pyrite with anomalous concentrations of copper, tungsten and gold. In mineral occurrences within these zones of phyllic alteration, the silver to gold ratio ranges from 3:1 to 20:1.

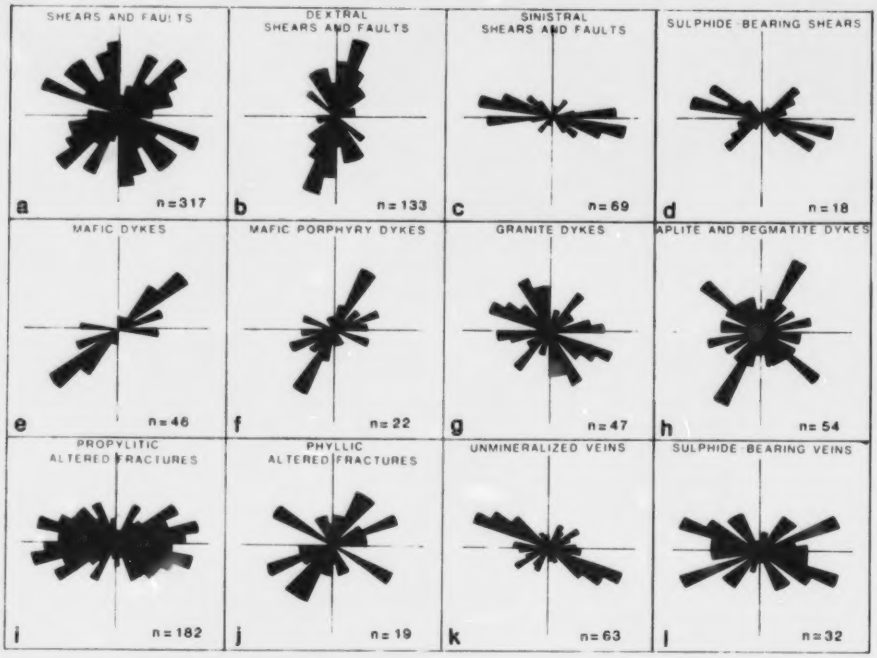


Figure 2. Rose diagrams illustrating the two-dimensional orientation of various structure features in the Phantom Lake area

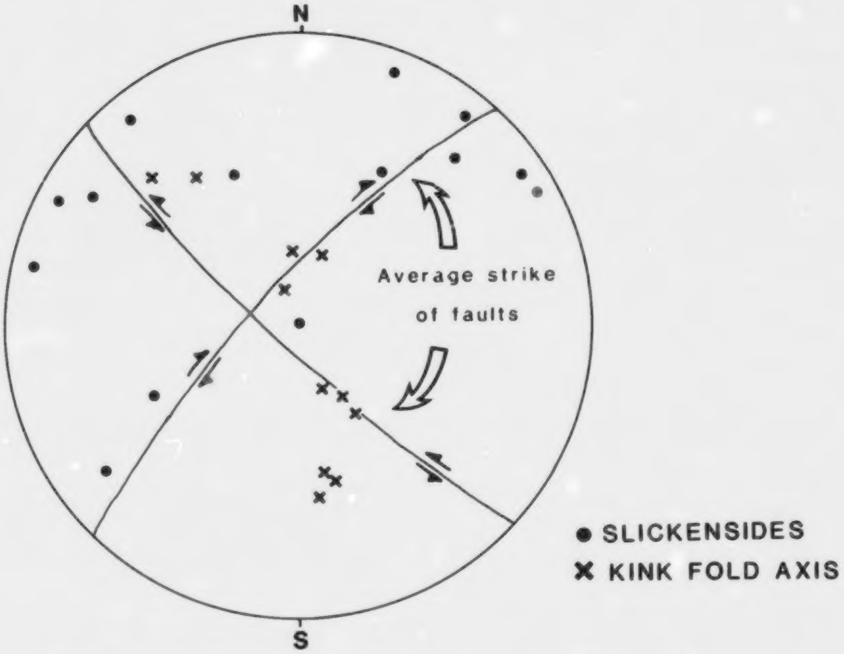

N
S
Average strike of faults
● SLICKENSIDES
✖ KINK FOLD AXIS

Figure 3. Stereographic projection on an equal area net of linear features and the average orientation of the strike-slip conjugate shear set that cross-cut the PLIC.

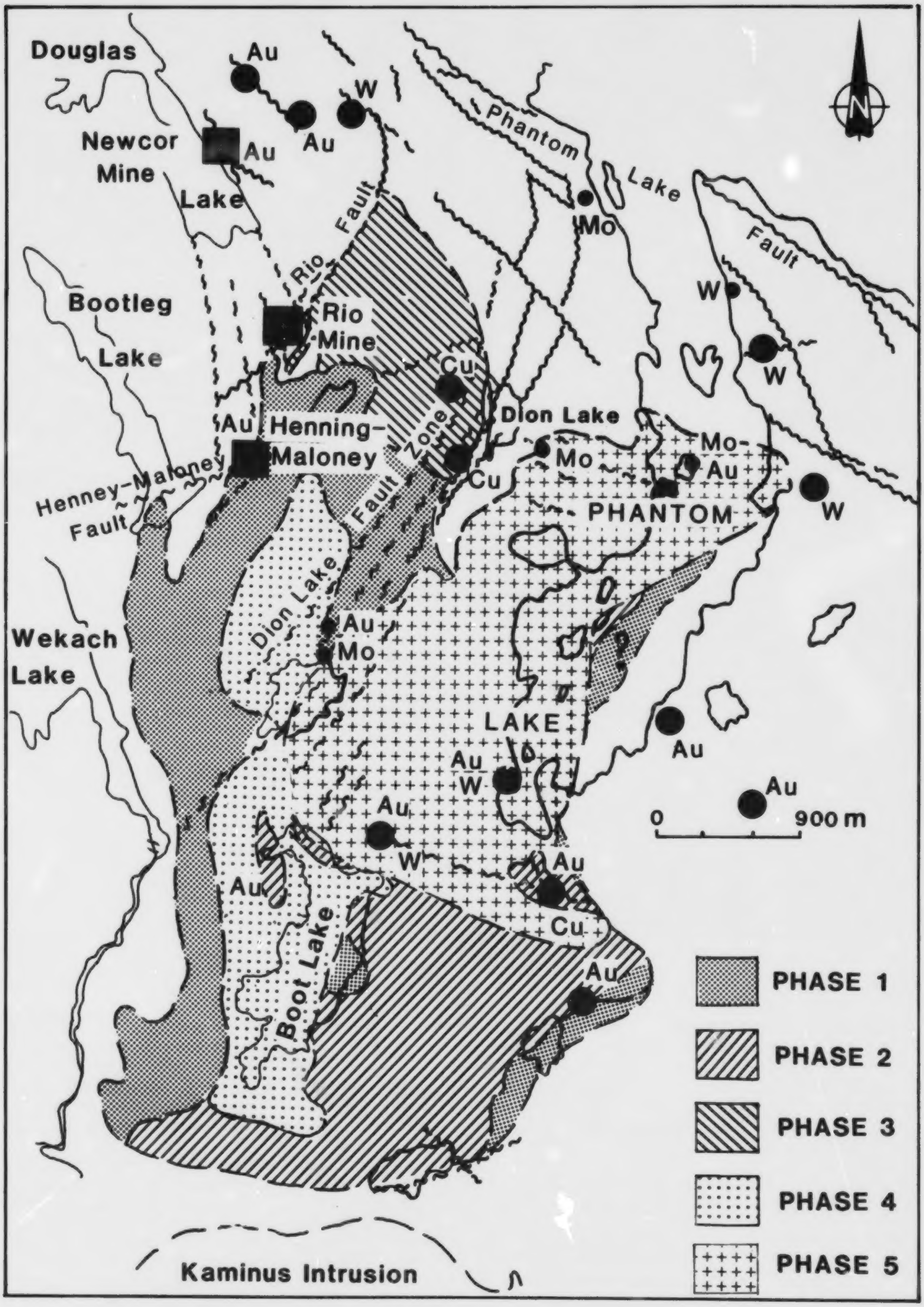

Douglas
Au
Au
W
Newcor Mine
Au
Lake
Phantom
Lake
Fault
Rio Fault
Bootleg Lake
Rio Mine
Mo
W
W
Cu
Au
Henning-Maloney
Zone
Dion Lake
Mo
Mo-Au
Henney-Maloney Fault
Fault
Cu
PHANTOM
W
Wekach Lake
Dion Lake
Au
Mo
LAKE
Au
Au
W
Au
0
900 m
Au
W
Au
Cu
Au
Boot Lake
Au
PHASE 1
PHASE 2
PHASE 3
PHASE 4
PHASE 5
Kaminus Intrusion

Figure 4. Internal zonation of the Boot Lake-Phantom Lake intrusive complex.

The third type of alteration is associated with quartz-carbonate vein-hosted gold mineralization and is typified by the assemblage quartz-chlorite-ankerite-pyrite. Alteration is restricted to the set of conjugate NNE-ESE faults, typically where they cross-cut mafic volcanic and intrusive rocks. Where the fault forms the contact between two rock types of differring competency, or crosses of large dyke at an angle, the alteration assemblage forms a halo around quartz-carbonate veins within the fault. This type of phyllic alteration and mineralization characterize the three past-producing gold deposits (Rio, Newcor and Henning-Maloney) along the northwest margin of the intrusive complex.

GOLD DEPOSITS

Three past producing gold mines are situated along the northwest margin of the PLIC (Figure 4). The Henning-Maloney and Rio deposits are hosted by NNE striking, dextral faults, and the Newcor is within a more northerly striking dextral fault. Slickensides in the faults which host the deposits plunge shallowly to the north, similar to slickensides within the other NNE striking faults that transect the PLIC.

Gold zones plunge steeply to the southwest at the Henning-Maloney and Newcor deposits. At the Rio deposit the entire zone of gold mineralization plunges steeply to the southwest, but high-grade shoots within the zone plunge steeply to the northwest. This added complexity at the Rio is due to the kinking of the northeast striking Rio Fault by a SSE striking dextral fault (Figure 4). The steep northwest plunge of these kinks is parallel to that of the high grade gold zones.

The mineralized zones plunge at approximately 90o to the motion on the host faults. A simple shear model dictates that, in a strike-slip fault, whereas slip within a shear zone parallels the direction of maximum extension, zones of maximum dilation would parallel the intermediate strain axis (Poulsen, 1986). It is feasible then, that gold deposition took place during the formation of the fault system.

LEAD ISOTOPE DATA

These analyses were obtained on galena samples in order to examine genetic and age inter-relationships between deposits and districts. The data (Figure 5) form a distinct linear trend. Deposits within single districts are quite uniform in composition, indicating local homogeneity of the mineralizing fluids. The closely similar compositions of galena from tungsten and gold deposits at Phantom Lake (Billy Boy, Rio, Douglas Tungsten and the W vein) indicate a genetic link between these, confirming the structural data which illustrated the similar timing of their emplacement. Similarly, most of the data for samples from the Snow Lake area form a cluster, but at a higher 207Pb/204Pb position than for the Phantom data. Only the samples from Rex-Laguna and the Century mine are more radiogenic.

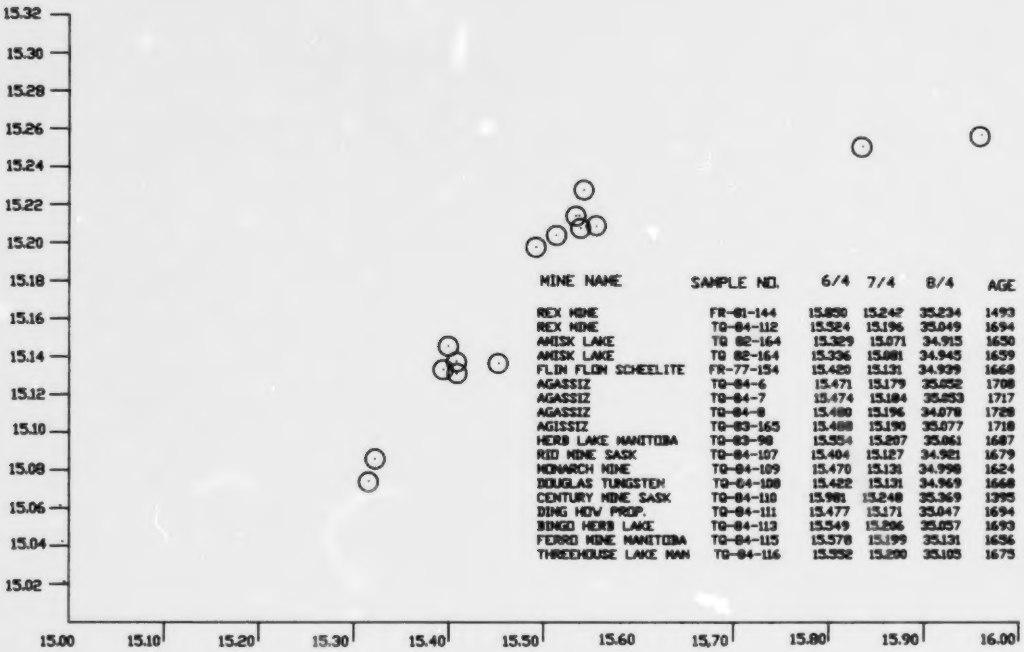
The linear distribution of data may be an isochron (m = 0.469+/-0.02), indicating that most of the gold deposits formed at about the same time. Alternatively, this may be a binary mixing line, and have no age significance. Using the Stacey and Kramers (1975) model system, the ages range from 1624 Ma to 1728 Ma (av=1683 Ma). Gordon et al. (1988) used the U/Pb ages from various plutons in the Flin Flon Belt and Kisseynew Sedimentary Gneiss Belt to establish the peak of regional metamorphism was between 1800 and 1820 Ma. However, K/Ar age determinations for the eastern part of Churchill Province (Wanless et al., 1965, 1974) are much younger, and similar to the lead isotope ages. The fact that the gold-associated alteration mineral assemblages overprint the peak metamorphic assemblage implies that 1820 Ma would be a maximum age for gold deposition within these epigenetic systems, and that the actual age may be closer to that established by closure of the Argon system. A major thermal event may have terminated about that time, and gold deposits were thus formed very late in the tectonic history of the region.

SUMMARY

The setting of gold mineralization in the Phantom Lake region can be used to define not only the timing of gold deposition, but the dynamics of the geological environment at this point in the history of the Flin Flon Domain.

Gold mineralization is spatially associated with an intrusive complex that represents the youngest igneous event in the Flin Flon Belt. The calc-alkaline, I-type nature of the complex is typical of magmas intruded into continental crust, while the texture of the phases and the presence of a contact metamorphic aureole indicates emplacement at a high level (Titley, 1982).

Zones of propylitic and phyllic alteration, with associated copper, tungsten, molybdenum, silver and gold centered around the PLIC are common characteristics of high-level porphyry systems (Titley, 1982). These alteration-mineralization events are controlled by various scales of fracturing and shearing that are a product of contraction of a porphyry system during cooling, and of an inhomogenous stress field that was active at the time of intrusion (Heidrick and Titley, 1982). In the case of the PLIC this stress involved a sub-horizontal shortening that resulted in the formation of the Cliff Lake-Ross Lake Fault Zone. The relationship of the intrusive complex and associated mineralization with a set of conjugate strike-slip faults suggests that intrusion took place late in the formation of the fault zone, when overloading of the crust during thrusting resulted in the reorientation of the axis of maximum extension from the vertical to the horizontal. Kinematic evidence indicates that gold deposition took place under the same deformation regime that controlled the emplacement of the intrusive complex and its related alteration.



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DING HOW PROP.	TQ-84-111	15.477	15.171	35.047	1694
BINGO HERB LAKE	TQ-84-113	15.549	15.206	35.057	1693
FERRO MINE MANITOBA	TQ-84-115	15.578	15.199	35.131	1656
THREEHOUSE LAKE MAN	TQ-84-116	15.552	15.200	35.105	1675

Figure 5. Lead isotope data taken from gold occurrences across the Flin Flon Belt. The center cluster of points includes occurrences in the Phantom Lake region (Rio, Douglas tungsten, Flin Flon scheelite).

The Phantom Lake deposits share some similarities with the Porgera porphyry-related gold deposit in Papua, New Guinea (Handley and Bradshaw, 1986). In both cases, the intrusion of the complex was controlled by a series of faults that continued to be active during the alteration and mineralization. The complexes both have a calc-alkaline affinity, and show strong REE fractionation, with mafic igneous phases characterized by primary hornblende. Alteration is carbonate-rich, and consists of an early phase of propylitic, followed by two phases of phyllic alteration. The first type of phyllic alteration is dominated by sericite-carbonate-pyrite, it is auriferous, and has developed along zones of high permeability. The second type is quartz-carbonate-chlorite-pyrite rich, with quartz veins containing free gold.

The possibility of gold-rich porphyry intrusions being present in this Early Proterozoic terrane opens another avenue for gold exploration. Irregardless of the genetic relationship of the gold to the Boot Lake-Phantom Lake intrusive complex, mineralization is controlled by faults formed late in the tectonic history of the belt. The similarity in the maximum age of gold mineralization deduced for the Phantom Lake region and that of gold deposits in the rest of the belt (Galley et. al., this volume) infers that the mineralizing event was large-scale, typified by zones of reverse faults across which the tectonic transport direction was east to west. A similar event described by Bleeker (1989) along the Churchill-Superior boundary implies a relationship between a regional-scale gold mineralizing event and the collision of the Early Proteroic Reindeer Zone with the Archean Superior craton.

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STRUCTURE AND HYDROTHERMAL ALTERATION, RICE LAKE GOLD DISTRICT, SOUTHEASTERN MANITOBA

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OBJECTIVES

The Archean Rice Lake Greenstone Belt (Figure 1) is Manitoba's most important lode gold district, accounting for nearly two million ounces (approximately 60 tonnes) of past gold production. The geology and gold deposits of this area have been intensively studied in the past but, with the revitalization of gold exploration in the 1980's, new initiatives were undertaken in 1984 by the Geological Survey of Canada and the Manitoba Mines Branch to further improve the level of geoscience documentation in this area, particularly as it pertains to the occurrence of gold. Designed to complement a concurrent mineral inventory by the Mines Branch, the present study was initiated to examine regional and local features that are directly related to known gold deposits in the Bissett and Beresford Lake areas. The study has emphasized three related topics: the relationship between gold-bearing structures and regional increments of deformation; recurring statigraphic affiliations as a guide to ore; the role of hydrothermal alteration, principally carbonatization, in the ore-forming process and its applicability as a guide to ore.

RESULTS OF THE STUDY

1) Geology and gold deposits of the Bissett area

Several aspects of the geological setting of gold deposits in the Bissett area were examined through detailed mapping (see area outlined in Figure 1; Ames, Poulsen, and Galley, 1985-1987) and through petrographic and geochemical follow-up.

As demonstrated by previous workers, the stratigraphic succession dips and faces northward with the exception of the arenites of the San Antonio Formation that occur on the on the overturned limb of a major syncline southwest of the Rice Lake shear zone (Figure 1). North and east of this shear zone, volcanic and epiclastic rocks, principally of dacitic composition, are intruded by sills of fine to medium grained gabbro (Figure 2a).

The epiclastic rocks that underlie much of Rice Lake are primarily volcanic conglomerates and sandstones, interpreted to be braided fluvial deposits derived from unconsolidated pyroclastic debris on the slopes of a stratovolcano (Tirschmann, 1987). The stratigraphically younger porphyritic dacite that occurs north of Rice Lake is composed of euhedral to broken plagiocalse crystals, lithic fragments, pumice-like fragments, amygdaloidal spherulitic fragments and irregular to rounded quartz crystals in a fine grained matrix. The presence of brecciated zones, intercalated tuffs and relict clastic textures favour a subaqueous pyroclastic origin for this unit (Tirschmann,1987).

The gabbroic sills that intrude the epiclastic sequence are all compositionally layered. Ames (1988) used petrographic and geochemical data to show that the sill which hosts the San Antonio deposit is composed of three different types of gabbro: fine grained gabbro of normal basaltic composition occupies the upper and lower margins of the sill; melagabbro, enriched in MgO, FeO and Ni, comprises approximately the lower one-third of the sill; and, leucogabbro that is relatively enriched in $Al2O3$ and $TiO2$ occupies the upper two-thirds. Similar patterns of magmatic differentiation were noted in a sill south of the Mine and in a large body of gabbro east of Rice Lake (Figure 1).

Rocks in the Bissett area are deformed to varying degrees. The most prominent evidence of ductile deformation is a penetrative schistosity that, on average, strikes N80°W and dips steeply northward. This foliation (S2) is axial planar to a large reclined syncline in San Antonio Formation arenites and locally overprints an earlier foliation (S1) that is sub-concordant with bedding in the Rice Lake Group volcanic and epiclastic rocks. A prominent mineral lineation (L2) is coincident with the intersection of S1 and S2. This lineation trends northward at the south shore of Rice Lake but,north of Rice Lake, it deviates increasingly to the east (Figurel), a condition that is thought to result from subsequent deformation (D3) adjacent to the Wanipigow Fault (Poulsen et al., 1986).

The most intense effects of deformation are recorded in ductile shear zones that are common throughout the area. They are typically heavily carbonatized and include two types: those, such as the Normandy Creek and Footwall shears (Figure 1) that are concordant with lithological layering and those, such as the Rice Lake shear, that are discordant. Although definitive evidence is lacking, the presence of "down-dip" lineation and the fact that the Rice Lake shear places Rice Lake Group volcanic rocks over younger arenites, indicate that at least some of these structures are dominantly reverse faults.

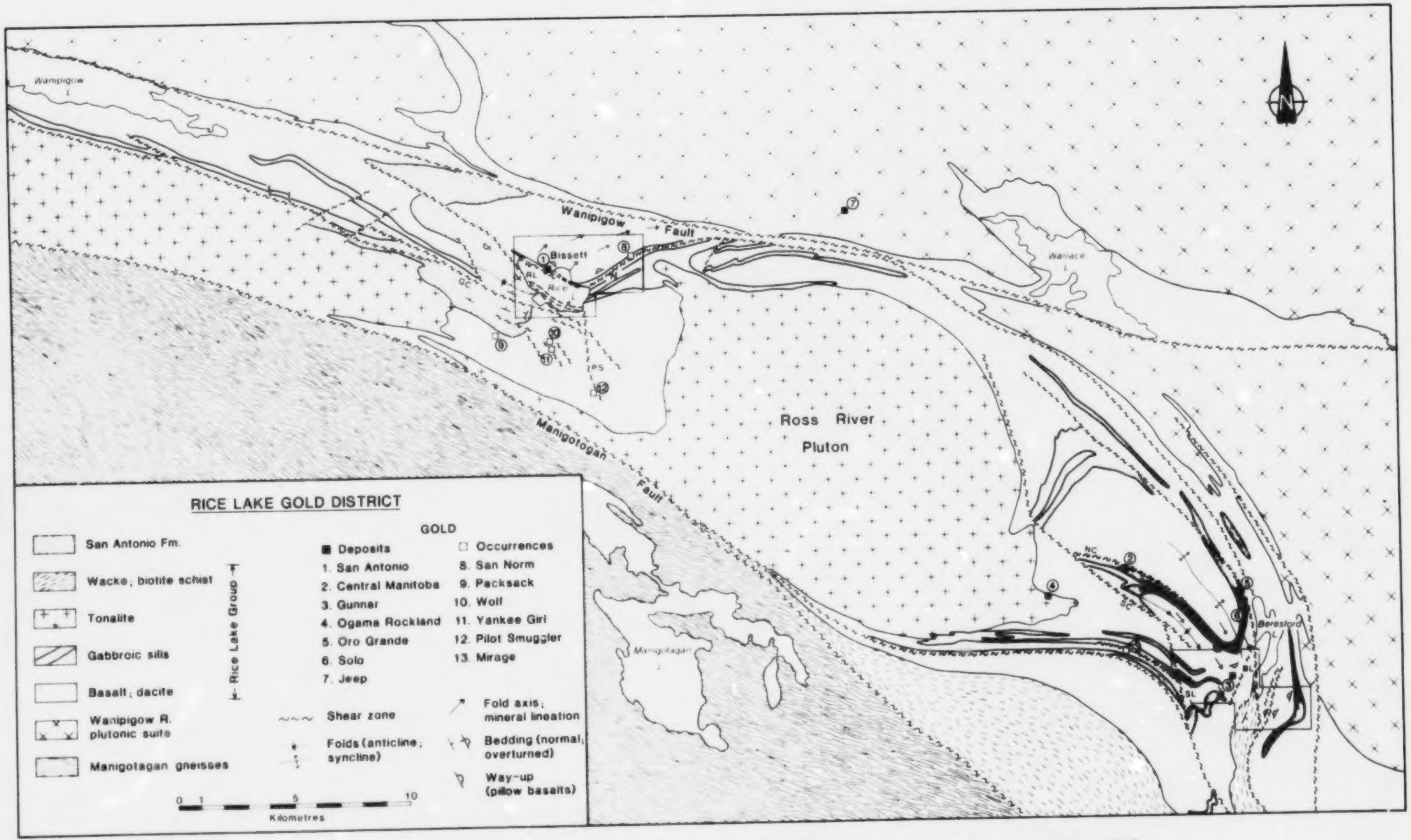
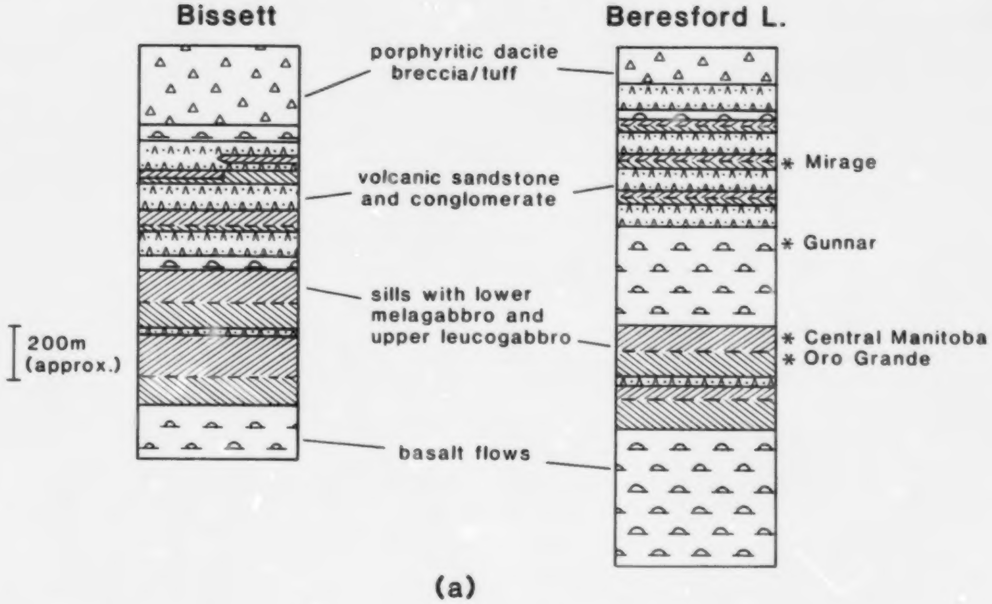

RICE LAKE GOLD DISTRICT
San Antonio Fm.
Wacke; biotite schist
Tonalite
Gabbroic sills
Basalt; dacite
Rice Lake Group
Wanipigow R. plutonic suite
Manigotagan gneisses
GOLD
Deposits
1. San Antonio
2. Central Manitoba
3. Gunnar
4. Ogama Rockland
5. Oro Grande
6. Solo
7. Jeep
Occurrences
8. San Norm
9. Packsack
10. Wolf
11. Yankee Girl
12. Pilot Smuggler
13. Mirage
Shear zone
Folds (anticline, syncline)
Fold axis; mineral lineation
Bedding (normal; overturned)
Way-up (pillow basalts)
0 1 5 10
Kilometres
N
Wanipigow L.
Wanipigow Fault
Bissett
RL
Rice
GC
PS
Wallace L.
Ross River Pluton
Manigotagan Fault
Manigotagan L.
NC
SC
Beresford L.
BL
SL

Figure 1: Geological map of the Rice Lake gold district (adapted after Stockwell, 1945; Weber, 1971). Important carbonatized shear zones include Rice Lake (RL), Normandy (N), Gold Creek (GC), Footwall (F), Pilot-Smuggler (PS), North Carbonate (NC), South Carbonate (SC), Beresford Lake (BL) and Stormy Lake (SL). The irregular rectilinear areas outlined near Bissett and Beresford Lake show the extent of 1:5,000 scale mapping conducted as part of this study.


Bissett
Beresford L.
porphyritic dacite breccia/tuff
volcanic sandstone and conglomerate
sills with lower melagabbro and upper leucogabbro
basalt flows
200m (approx.)
* Mirage
* Gunnar
* Central Manitoba
* Oro Grande
(a)

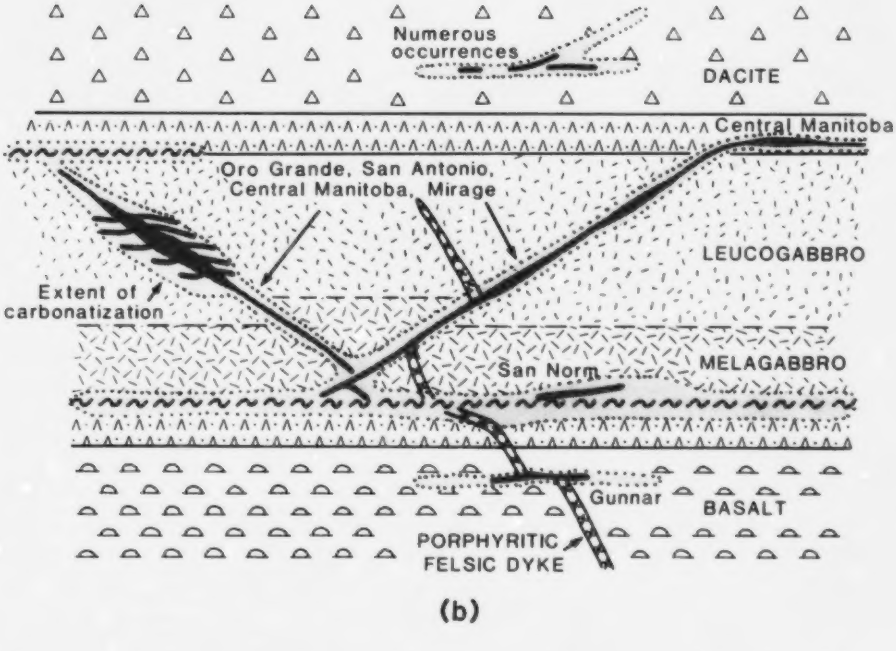

Numerous occurrences
DACITE
Central Manitoba
Oro Grande, San Antonio, Central Manitoba, Mirage
LEUCOGABBRO
Extent of carbonatization
San Norm
MELAGABBRO
Gunnar
BASALT
PORPHYRITIC FELSIC DYKE
(b)

Figure 2: a) Schematic stratigraphic sections for the Bissett and Beresford Lake areas. The stratigaphic positions of selected gold deposits are indicated by asterisks.
b) Schematic geological model that illustrates the interrelationships of stratigraphic position, structure and distribution of hydrothermal alteration for various gold deposits in the Rice Lake district.

2) Structure of the San Antonio Gold Deposit

W. Brisbin and S. Lau of the University of Manitoba (DSS contracts OST84-00088 and 23233-6-0864-ST) undertook a re-examination of the structural geology of the vein system at the San Antonio Mine and analysed the relationship between these veins in a competent gabbroic host and the fabric of adjacent, relatively less competent, volcanic rocks of the Rice Lake Group.

Five different fracture sets of successively decreasing relative age have been identified within the northeasterly dipping gabbroic sill that hosts the deposit:

i) The oldest set is transverse to the sill and is filled by dykes of mafic and intermediate bulk composition. They are interpreted to be brittle extensional fractures of synvolcanic origin that have been subsequently rotated into their present position.

ii) Complex, elongate lens shaped zones of intensely fractured and mineralized host rock, termed "stockworks" are confined to the sill in en echelon fashion. Thirty steeply dipping stockworks have been identified to date and several of these attain thicknesses of ten metres. The stockworks typically comprise three structural elements: an inner central quartz vein; a central breccia zone composed of angular,altered wall rock fragments cemented by vein quartz; and a peripheral zone containing arrays of extensional, sigmoidally shaped "ladder veins" that are oriented at a mean angle of 45° to the stockwork zones. The stockworks, a major source of ore in the mine, are interpreted to be brittle shear zones that have formed in two stages, an initial sinistral reverse movement to account for the orientation and sigmoidal shape of the ladder veins, followed by a dextral reverse movement to account for the observed dextral displacement of dykes cut by the central quartz veins.

iii) Arrays of northeasterly striking and northwesterly dipping quartz veins are also important sources of ore in the mine. These veins occupy central fractures in sinistral reverse ductile shear zones that comprise intensely foliated and lineated schists derived from the host rock. The shear veins, although of similar composition and gold grade as those of the stockworks, rarely exceed a width of one metre and tend to pinch and swell along strike and down dip.

iv) The most prominent fracture set that post-dates ore-bearing veins consists of northeasterly striking and southeasterly dipping quartz carbonate veins, less than 50 centimetres wide, that occupy narrow ductile shear zones of dextral reverse sense. These structures offset dykes, stockworks and mineralized shear veins thereby having a disruptive effect on the continuity of ore.

v) The youngest set comprises post-ore brittle faults of dextral reverse sense that contain vein breccias, typically 10 centimetres wide, that are composed of quartz, calcite and chlorite.

Apart from the differences in inferred relative ages of each of these fracture sets, conventional paleostress analysis (Lau,1988) further indicates that the fracture sets do not conform to a common stress field. This implies that pairs of sets have not developed as conjugates but that fracturing took place over several increments of deformation during which there was rotation of principal stress axes relative to the boundaries of the sill.

The five fracture sets interact to produce a complex three-dimensional network (Lau,1988) with a pronounced northeast plunge for the deposit as a whole. This axial direction corresponds to a mineral elongation that is observed in adjacent volcanic rocks of the Rice Lake Group. Analysis of strain in porphyritic dacite north of the San Antonio Mine indicates that this mesoscopic lineation is a product of deformation of both phenocrysts and matrix; the phenocrysts display only strong components of flattening whereas matrix strain resulted from variable proportions of both flattening and stretching. By analogy, the rheological model that best accounts for the large-scale development of the vein system at San Antonio is one of relatively brittle failure of a stiff or elastic member (a gabbroic sill) in a ductile matrix (volcanic rocks) undergoing flattening and extension. During this deformation, the sill either rotated with respect to a fixed stress field or remained fixed in a changing stress field.

3) Hydrothermal Alteration at the San Antonio Mine

Several different types of wallrock alteration were recognized by mine staff at San Antonio in the 1940's and were mapped routinely as a guide to locating ore. D.E. Ames (Ames,1988; Ames et al.,1989) conducted an in depth study of the origin of this alteration and investigated its zonation with respect to ore-bearing veins.

Carbonatization of the gabbroic sill at San Antonio postdates its regional metamorphism to greenschist facies assemblages containing varying proportions of epidote, actinolite, chlorite, albite, quartz and titanite. Carbonatization subsequently produced alteration mineral assemblages which pseudomorphically replace the metamorphic minerals and which define alteration isograds that record changes in these assemblages. In the leucogabbro, these isograds correspond to the following changes (Ames et. al., 1989):

i) actinolite + epidote + CO_2 = chlorite + calcite + quartz

ii) titanite + CO_2 = rutile + calcite + quartz

iii) chlorite + calcite + albite + CO_2 = paragonite + quartz

+ ankerite + H_2O

iv) quartz + paragonite + K^+ = albite + muscovite + H^+

These isograds are zonally distributed about the gold-bearing structures such that isograd (iv) is innermost and isograd (i) is outermost. The alteration assemblages and their zonation are similar in the vicintity of stockworks, shear veins and veins in NE-SE fractures, indicating that the composition of the hydrothermal fluids remained relatively constant over the time span during which these different vein generations were formed. The alteration zonation about veins hosted by melagabbro is only recorded by isograds (i) and (ii) and, with increasing alteration, ankerite was formed from tremolite and calcite, a reflection of the more mafic bulk composition of this host rock.

Mass balance calculations (Ames,1988) show that CO_2, S and K were added to the gabbroic rocks from the hydrothermal fluid with a change in the oxidation state of iron towards reducing conditions. Boron and sodium were also added at the contacts of veins in the form of metasomatic tourmaline and albite. Pyrite is most directly related to the occurrence of gold and formed after muscovite and ankerite. Quartz-calcite-chlorite veins crosscut and replace ealier formed alteration minerals.

The observed gradients in alteration have been analysed by a model system (Ames,1988) that treats CO_2 and K^+ as mobile components in a mass balance calculation. The observed isograds can form during a progressive increase in mole fraction of CO_2 during isothermal, isobaric metasomatism. The observed assemblages restrict the temperature of alteration to less than 440°C.

4) Geology and Gold Deposits of the Beresford Lake area

The geological setting of gold in the Beresford Lake area was re-examined through reconnaissance and detailed outcrop mapping (Brommecker et al.,1989; Poulsen et al.,1989).

Based on the results of his 1:5,000-scale mapping in the area of the Gunnar Mine (see area outlined in Figure1), Brommecker established a new structural chronology which appears to apply as well to the greater Beresford Lake area. He identified evidence of three separate increments of deformation. The youngest of these (D3), a shortening from the NNW, produced locally developed crenulation cleavage, kink bands and conjugate sets of relatively brittle faults and shear zones. These structures overprint D2 features which include mesoscopic folds (F2), a penetrative axial plane schistosity (S2), and a pronounced mineral and object lineation (L2) that is coincident with F2 fold axes (Figure 1). Shortening recorded by D2 was from the NE and also resulted in the common development of D2 shear zones. The earliest deformation (D1) is inferred from local schistosities and shear zones that are overprinted by both D2 and D3 stuctures. One large structure of D1 generation, the Beresford Lake Deformation Zone (Figure 1), has been identified directly east of the Gunnar Mine (Brommecker et al., 1989). Gold and carbonatization in the Beresford Lake area are preferentially related to D1 and some D2 shear zones. For example, the concordant North Carbonate shear zone at the central Manitoba Mine (Figure 1) is overprinted by S2 cleavage and cut by the South Carbonate shear zone which is of D2 generation.

With the exception of the Ogama-Rockland deposit which is hosted by tonalite of the Ross River pluton, most significant occurrences of gold are hosted by rocks of a resricted stratigraphic interval dominated by epiclastic volcanic rocks, basalt flows and layered gabbroic sills(Figure 2a). Judged by the detailed mapping of layers and bulk chemical trends, the seqence of layering is similar to that in the Bissett area, from a melagabbroic base to a, commonly quarz-bearing, leucogabbroic top. Quartz veins at the Central Manitoba, Mirage, and Oro Grande deposits are hosted directly by leucogabbro but the epiclastic and basaltic rocks in the Beresford Lake area also host significant veins.

5) Carbonatization as a Guide to Gold in Rice Lake Belt

L. Diamond and G. Skippen, Carleton Univerity (DSS contract 23233-6-1173/01-ST), conducted a reconnaissance study of selected veins in Rice Lake Belt to characterize fluid inclusion compositions and wallrock alteration, to explore relationships between fluid inclusion compositions and ore grade and to investigate applications of these results to gold exploration. The localities studied include the San Antonio, Packsack, Yankee Girl, Wolf and Pilot-Smuggler in the Bissett area and the Gunnar, Central Manitoba, Oro Grande and Solo in the Beresford Lake area (Figure 1). Some of the veins that were studied contain gold of ore grade, whereas others are barren.

All of the veins examined contain fluid inclusions that, at room temperature, consist of a CO_2 liquid and weakly saline water. In addition, some inclusions contain CO_2 vapour and accidental solid inclusions of mica, carbonate and rutile. In each of the rare cases in which petrographic criteria prove unequivocal contemporaneity between native gold and an assemblage of fluid inclusions, the fluids are invariably CO_2-bearing. Petrography, microthermometry, laser Raman spectroscopy and Secondary Ion Mass Spectrometry (SIMS) results show that the average vein-forming solutions comprised (in mole%): H_2O= 91, CO_2 = 6.1, Na = 1.3, K = 0.05, Ca = 0.05, Cl = 1.45. All veins contain less than detectable limits of N_2 (<0.06) and H_2S (< 0.08) and veins from Bissett area contain less than detectable (<.006) CH_4 whereas those from Beresford Lake contain up to 0.46 mole percent CH_4.

The proportions of the two major components in the H_2O-CO_2 inclusions are typically variable within a single sample and are best interpreted to be the result of ductile deformation of populations of inclusions that were once homogeneous. In some cases, however, populations of inclusions having constant phase proportions are preserved. Both H_2O-rich and CO_2-rich populations of this type have been observed and, in rare cases, have been found to co-exist in the same sample, a condition that suggests unmixing (retrogade boiling) of a homogeneous H_2O-CO_2 fluid. Although not all quartz generations in a given vein precipitated from boiling solutions, the P-T conditions of vein formation, shear deformation, and gold precipitation straddled the miscibility boundary of the hydrothermal fluid at approximately 200 to 240°C and 500 to 700 bars.

In addition to the H_2O-CO_2 inclusions, several veins also contain later generations of saline aqueous fluid inclusions, locally with detectable CH_4 but with no CO_2. Such inclusions occur in quartz vug crystals and brittle fractures. Similar inclusions were observed in small quartz-chlorite veinlets that are common regionally. The fluids responsible for forming such veinlets and the late generation inclusions in larger veins probably represent regionally abundant metamorphic fluids or younger groundwaters that are unrelated to gold mineralization.

No correlations have been found between fluid compositional characteristics and ore grade; the same boiling fluid appears to have formed both barren and auriferous veins. Also no correlation was found between ore grade and the extent of wallrock carbonatization. This suggests that the precipitation of gold in veins is to a large extent independent of wallrock buffering and that high fluid-rock ratios were prevalent at the site of deposition.

A fluid inclusion crushing-stage technique was evaluated as a method to distinguish veins with abundant CO_2-H_2O inclusions from those containing the more common saline "regional" fluids. Easily carried out in the field, the technique provides rapid, inexpensive identication of veins of the first type; its most useful potential applications are likely to be in reconnaissance exploration and in the identification of the provenance of quartz grains in till.

Exploration Model

Although there are a multitude of gold occurrences in Rice Lake District, each with its unique attributes of structure, host rocks and alteration, the results of this study permit the formulation of several first order generalizations which pertain to the most significant deposits (Figure 2b). Points of consideration as the basis of an exploration model in this district include:

i) At a regional scale, most signicant deposits occur in a restricted stratigraphic interval that marks the transition from volcanic units that are predominantly composed of basalt to those composed of porphyritic dacite. The interval of transition is marked by the presence of epiclastic rocks, extensive gabbroic sills and locally, banded iron formation. Although the full significance of this lithological association is not obvious, the structural anisotropy afforded by the intercalation of these rock types is one factor that locally controls the location of veins.

ii) Two dominant types of structures host productive veins: veins that are longitudinal with respect to lithological contacts are a product of layer-parallel shear whereas those that are transverse are likely the result of local layer-parallel elongation and shortening of the stiffest members of the stratigraphic sequence. Not all such structures formed simultaneously, nor are they all prospective hosts for auriferous veins. Early formed reverse faults are most favourable, but these are not easily distinguishable from younger structures on the basis of orientation alone because successive increments of deformation resulted in probable reorientation, overprinting and reactivation of the earliest structures.

iii) CO_2-bearing fluids of similar composition were present during the development of virtually all veins and shear zones, regardless of their relative age and gold content. The intensity of carbonatization adjacent to stuctures is not directly related to gold deposition nor to progessive changes in fluid composition. However there is a direct relationship between carbonatization and fracturing and, in that sense, the recognition of such alteration is a useful guide to potential auriferous structures, if not to gold itself.

These generalizations can be applied to the identification of two types of future exploration targets in Rice Lake district. First, there is the potential offered by the re-evaluation of existing deposits and occurences along strike and at depth. The San Antonio, Central Manitoba, Oro Grande and Mirage are notable in this respect. In all of these cases, exploration down the inferred local plunge as opposed to down lithological dip should be a paramount consideration. Second, there are abundant opportunities for new discovery. The transitional stratigraphic package containing epiclastic volcanic rocks and gabbroic sills is regionally extensive (Figure 1) and is not everywhere well exposed. There are several situations where structural disruption of this sequence by longitudinal and transverse shears is indicated and these include: the area eight to ten kilometers west northwest of the San Antonio Mine, the gabbroic sill underlying the southern part of Rice Lake, the area directly west of Stormy Lake and the area approximately two kilometers southeast of Beresford Lake. Where iron formation is a significant component of the sequence, as in the last of these, it too should be a prospective host for gold.

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LA RONGE STRUCTURAL STUDIES

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Geological Survey of Canada

OBJECTIVES

A study of gold deposits in the La Ronge domain was initiated in 1984 by the Geological Survey of Canada under the terms of the Canada-Saskatchewan Mineral Development Agreement(1984-1989). Designed to complement the concurrent Precambrian mapping program by D. Thomas and C. Harper of the Saskatchewan Geological Survey, the ojectives of the project were to examine those structural features of the La Ronge domain that are directly related to ore; to undertake detailed structural analysis of selected gold deposits; and to address metamorphic and stratigraphic controls where appropriate. Most of the work was undertaken in the Star Lake area which (Figure 1), during the period 1984-1989, evolved from being the site of a single developed prospect to Saskatchewan's foremost gold district with two producing mines and a third at an advanced stage of development. Reconnaissance level examination of deposits at Waddy and Laonil Lake was also undertaken for comparison with the Star Lake deposits.

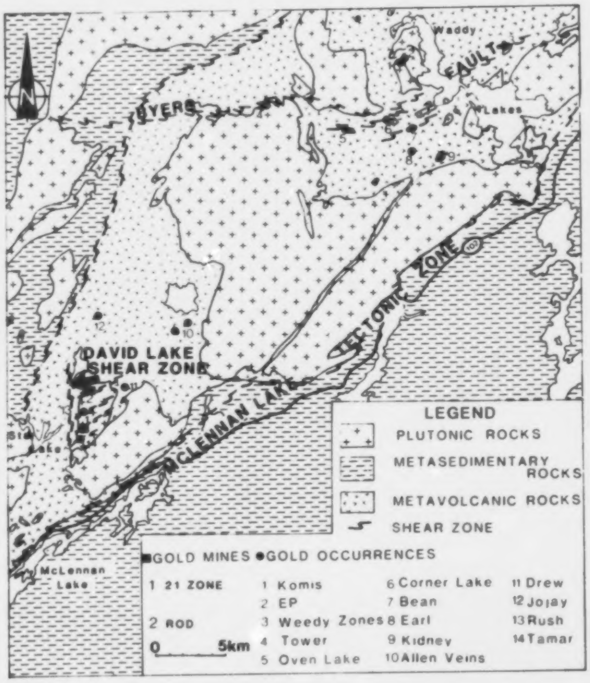

N
Waddy
FAULT
Lakes
BYERS
5
6
7
8
9
102
TECTONIC ZONE
12
10
DAVID LAKE
SHEAR ZONE
11
McLENNAN LAKE
Sid
Lake
McLennan
Lake
LEGEND
PLUTONIC ROCKS
METASEDIMENTARY ROCKS
METAVOLCANIC ROCKS
SHEAR ZONE
GOLD MINES
GOLD OCCURRENCES
1 21 ZONE
2 ROD
0 5km
1 Komis
2 EP
3 Weedy Zones
4 Tower
5 Oven Lake
6 Corner Lake
7 Bean
8 Earl
9 Kidney
10 Allen Veins
11 Drew
12 Jojay
13 Rush
14 Tamar

Figure 1: Location map of gold deposits and major geological features in the northern part of the La Ronge domain; based on mapping by the Saskatchewan Geological Survey.

RESULTS OF THE STUDY

Field work for the project was carried out in the summers of 1984 through 1987 and interim reports of progress were released sequentially (Poulsen et al.,1985; Poulsen et al.,1986a; Poulsen et.al.,1986c; Ames et al.,1987; Poulsen et al.,1987). This report integrates these findings and summarizes the important features associated with the gold deposits.

Plutons

There is an exceptionally strong regional spatial correlation between the gold deposits of the La Ronge area with a suite of syntectonic plutons that range in composition from gabbro and diorite, to quartz monzonite and granite. The plutons are typically circular to elliptical in plan and one to ten kilometers in diameter. They contain mainly medium-to coarse-grained granitoid rocks and mapping by the Saskatchewan Geological Survey has demonstrated that some plutons are relatively homogeneous in composition whereas others are concentrically zoned. The Star Lake pluton shows the most striking example of zoning (Figure 2a) but it is clear that the observed compositional variations are of little significance to the localization of gold.

The syn- to late-tectonic emplacement of the Star Lake pluton is deduced from three observations:

i) they are metamorphosed and penetratively deformed; the metamorphic foliation, S1, defined mainly by the dimensional orientation of biotite aggregates, parallels the contacts of the Star Lake pluton (Figure 2) and is most intensely developed near its contacts; despite its variable orientation, the foliation, on average, strikes north northeast and dips 60° west northwest, parallel to external (S1) foliation in adjacent metavolcanic rocks

ii) the marginal phases of the Star Lake pluton contain abundant xenoliths, some of which possess a metamorphic foliation that pre-dates S1, perhaps representing an earlier stage in the development of S1. Xenoliths, in general, are elongate parallel to S1.

iii)the Star Lake pluton lacks a definitive contact aureole that can be distinguished from regional metamorphic assemblages

The observed concentric development of foliation with respect to its contacts provides an indirect indication of the three-dimensional structure of the Star Lake pluton. If the parallelism of foliation and contacts, as observed in strike, is maintained with respect to dip, the prevailling dip of the foliation at 60° to the west northwest would also suggest a similar trend and plunge for the main mass of the pluton.

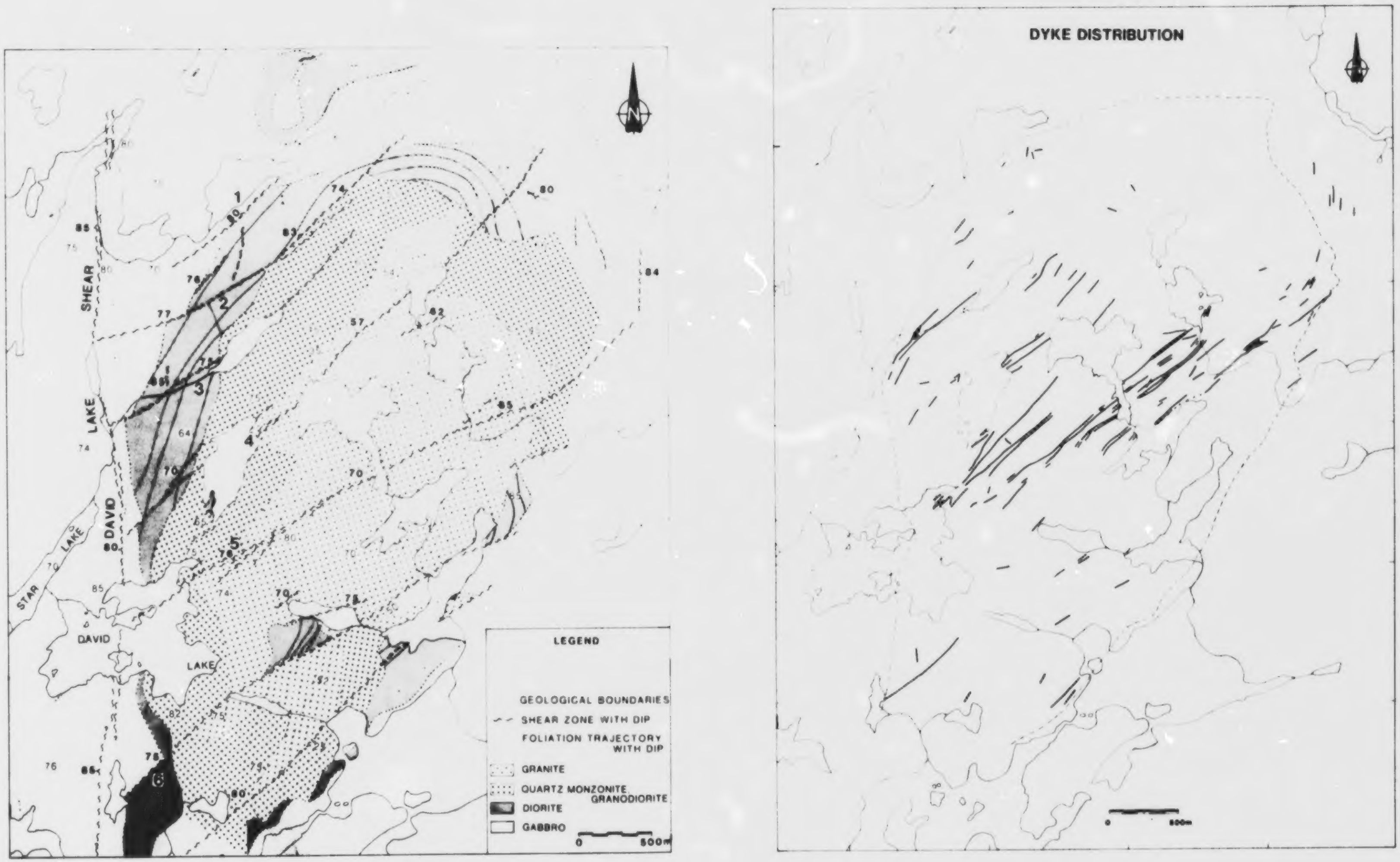
Dykes

The Star Lake pluton is cut by a swarm of dykes of the same range of compositions as the pluton itself. Dykes of this swarm are commonly present in the ore environment, raising the question of their relative importance in the localization of gold. Detailed mapping of these dykes by D. Ames, A. Galley and assistants (Figure 2b) shows that the dykes have a wider distribution than the occurrences of gold. The dykes vary in composition from gabbro to aplite, with quartz monzonitic dykes being most abundant. Cross-cutting relationships are not everywhere the same but, in general, dykes of increasingly felsic composition are progressively younger than mafic ones. The dykes strike on average N50°E and, where determined by diamond drilling, have steep dips. Their thicknesses vary from a few centimeters to 10 meters.

All dykes were metamorphosed along with the pluton and are foliated to varying degrees. No correlation was found between the intensity of foliation in a particular generation of dykes and their relative age. The intensity of foliation in dykes is rather a function of their proximity to younger shear zones as described below.

Mylonitic Shear Zones

The structural features most directly related to the occurrence of gold are mylonitic shear zones. In the Star Lake area such shear zones strike N60°E, dip steeply and are up to 30 meters thick. They are typically spaced 400 to 500 meters apart and range from one to four kilometers in strike length. The shear zones contain protomylonite and mylonite that are derived by the tectonic reduction in grain size of the plutonic host rocks. Apart from a well developed mylonitic foliation that dips steeply northward at angles (70° to 80°) shallower than those of the shear zones, the mylonitic rocks are also characterized by a pronounced down-dip mineral lineation defined by the rod-like shape of feldspar porphyroclasts and by elongate biotite aggregates.


SHEAR
LAKE
DAVID
STAR
LAKE
DAVID
LAKE
1
2
3
4
5
6
LEGEND
GEOLOGICAL BOUNDARIES
SHEAR ZONE WITH DIP
FOLIATION TRAJECTORY WITH DIP
GRANITE
QUARTZ MONZONITE GRANODIORITE
DIORITE
GABBRO
0
500m
DYKE DISTRIBUTION
0
500m

(a)

(b)

Figure 2: a) Structural geology of the Star Lake area (this study and taken from Poulsen et. al.,1987). Gold occurrences (bold numbers) include **1**, Decade; **2**, Rod (Jolu); **3**, Rush; **4**, Blindman; **5**, 21 Zone (Star Lake Mine); **6**, Tamar. b) Distribution of dykes in the Star Lake area (this study and taken from Ames et. al., 1987).

Most shear zones appear to have localized independently but in some cases there is a good spatial coorelation between shear zones and dykes. A common situation, observable at all scales, is for shear zones and dykes to be coincident along part of their course. Over such intervals, it is common for the shear zone to be partly, or entirely, confined to a dyke that is weaker than adjacent coarse-grained plutonic rocks. These intervals are therefore shear zone segments that differ slightly from the overall shear zone trend. The resulting jogs created by the merging of these segments (Figure 3a) with the main shears probably account for the increased dilatancy, as evidenced by the presence of vein quartz, where shear zones and dykes interact. This interaction also accounts for the observation that dykes of a particular generation are intensely foliated at some localities but possess only the weak metamorphic foliation (S1) at others.

The following characteristics suggest that the shear zones are high angle dip-slip ductile faults that have displaced rocks on the southeast upward with respect to those on the northwest:

i) mineral lineations typically have a steep pitch within the mylonitic foliation;

ii) the mylonitic foliation dips northward at a shallower angle than the shear zones;

iii) rare extensional crenulation cleavage cuts the mylonitic foliation at an acute angle as viewed parallel to the mineral lineation and its asymmetry with respect to the mylonitic foliation is consistent with south-side-up;

iv) adjacent to the north sides of shear zones, the pre-existing metamorphic foliation (S1) is deflected upwards;

v) dykes that are cut by shear zones are commonly offset dextrally in plan view; where this component offset can be resolved parallel to a mineral lineation, it is compatible with south-side-up displacement.

Major Fault Zones

Although small shear zones, of the type described above, have a considerable influence on the local occurrence of gold within intrusions, mapping by the Saskatchewan Geological Survey has demonstated that larger scale faults such as the McLennan Lake Tectonic Zone and the Byers Fault may influence its regional occurrence. As part of the present study, a third structure of this type, the David Lake Shear Zone, was outlined in the Star Lake area. All of these structures were studied at a few specific localities.

The McLennan Lake Tectonic Zone marks the southeastern limit of the La Ronge Domain. Mapping of a well-exposed section across it (Poulsen et al., 1987) showed that, at a larger scale, there are many similarities in structural style between this structure and the smaller shear zones within the Star Lake pluton. Rocks within the zone acquired intense foliation and down-dip lineation at amphibolite facies metamorphic conditions. Asymmetric z-shaped folds and s-shaped boudins overprint the foliation and have axes that are parallel to the strong mineral lineation. Brittle faults, cataclasite and pseudotachylite are common on the southeastern, footwall side of the northwesterly-dipping structure. These brittle faults have likely served to exhume the deep roots of this kilometer-wide ductile fault.

The Byers Fault is an 80 meter wide zone of intensely foliated and lineated metavolcanic rocks that strikes east northeast and dips steeply north northwest. Asymmetric z-shaped kink folds with axes parallel to steeply plunging mineral and clast lineations, as well as conjugate brittle shear fractures and hematitic cataclasites, overprint and disrupt the foliation.

The David Lake Shear Zone strikes north-south and dips steeply west. Less than 100 meters wide, it was traced along strike for five kilometers although it could be significantly longer and likely merges northward with the Alpat Lake Tectonic Zone (Figure 1). Folded mylonitic foliation, steep mineral lineation and late brittle fractures in the David Lake Shear are comparable to those in the Byers and McLennan Lake structures.

All of the major faults have a similar history of development: early ductile shearing of dip-slip (reverse ?) type was followed by predominantly dextral, strike-slip overprinting of increasingly brittle nature. This may be explained either by dextral transpression in which there is concurrent steep stretching or by early thrusting followed by dextral wrenching.

Gold Deposits

Throughout the La Ronge Domain gold is localized in quartz veins that occur either discontinuously along shear zones (Weedy, Star Lake, Jolu) or in extensional veins adjacent to shear zones (Rod South, Komis). Vein material in shear zones is localized in shoots that typically plunge at a high angle to observed mineral lineations. There is a tendency

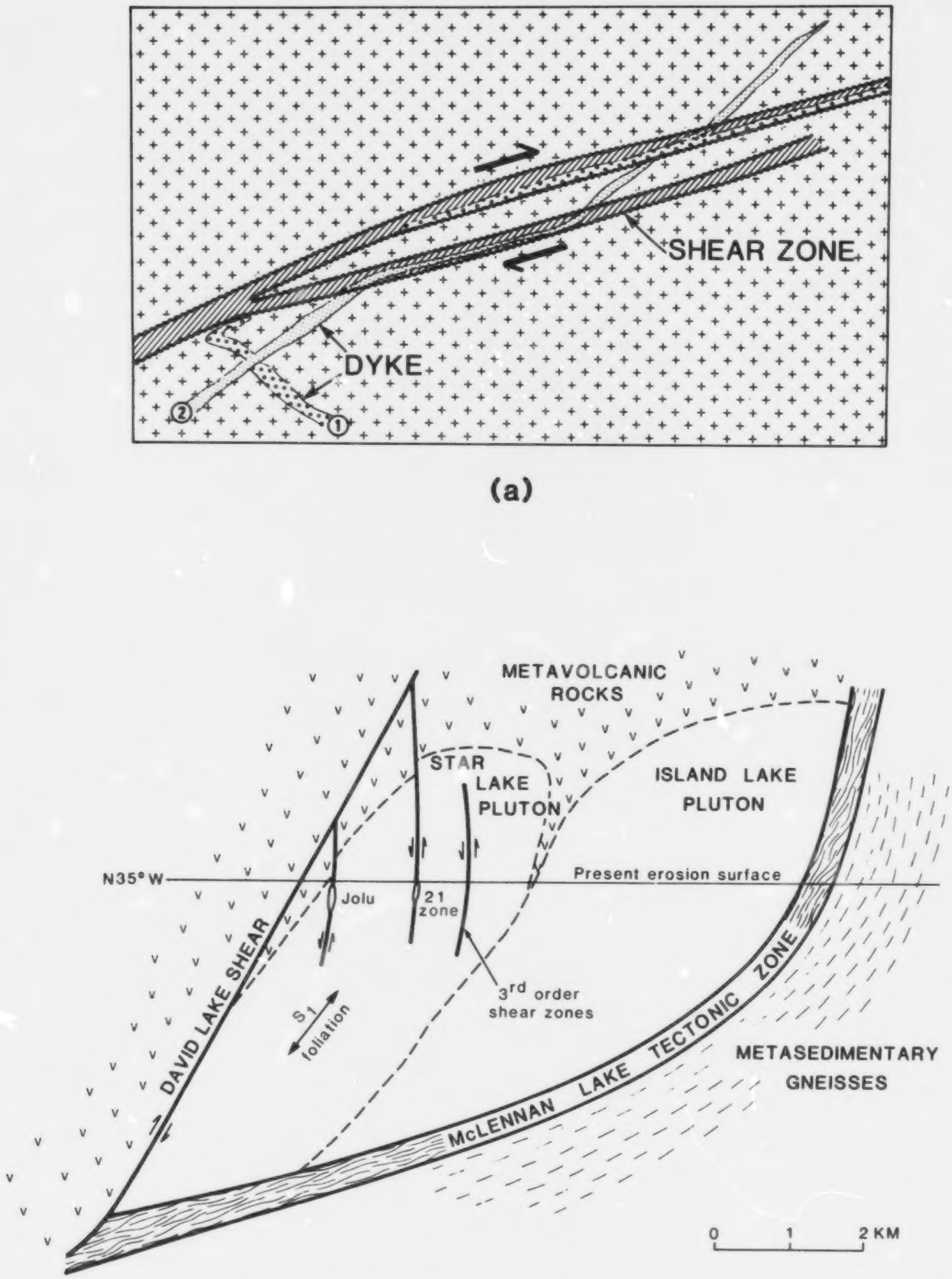

SHEAR ZONE
DYKE
②
①
(a)
METAVOLCANIC ROCKS
STAR LAKE PLUTON
ISLAND LAKE PLUTON
N35° W
Present erosion surface
Jolu
21 zone
3rd order shear zones
S1 foliation
DAVID LAKE SHEAR
McLENNAN LAKE TECTONIC ZONE
METASEDIMENTARY GNEISSES
0
1
2 KM
(b)

Figure 3: a) Schematic diagram illustrating the common relationship between dykes and shear zones in the Star Lake Pluton (taken from Poulsen and Robert, 1989). b) Schematic conceptual model showing the relationship between gold and faults. The line of cross-section is taken through the Star Lake area.

for shoots to localize where shear zones bifurcate or where they intersect dykes. Native gold occurs in veins as inclusions and fracture-fillings in quartz and sulfide minerals. Hydrothermal alteration around the deposits is minimal and typically is restricted to sericitization that extends less than one meter from veins. Hematization is a more extensive form of alteration that is present near many gold occurences but one that appears to be related to late brittle fracturing rather than ore forming processes.

SUMMARY

The results of structural studies carried out during this project allow formulation of a conceptual model (Figure 3) that links the localization of gold in the La Ronge Domain to regional and local faulting. Three orders of faults are recognized. The first-order McLennan Lake Tectonic Zone is not a direct locus for gold but is of structural importance in that it is likely the master fault that had a controlling influence on the formation of its subsidiary structures. Second-order structures such as the Byers Fault and the David Lake shear zone, in turn, are linked to third-order mineralized shear zones. The history of faulting in structures of all sizes has been the same. Field relationships suggest that quartz veins, sulfide minerals and gold were deposited relatively early in this fault history. Host rocks play a relatively passive role but intrusive rocks appear to provide sufficient mechanical anisotropy to create anomalous loci for fracturing and generation of dilatancy.

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METALLOGENY OF MAFIC AND ULTRAMAFIC ROCKS OF THE TRANS- HUDSON OROGEN OF NORTHERN SASKATCHEWAN AND MANITOBA

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Geological Survey of Canada

Forty-four different localities from within the Trans- Hudson Orogen of northern Saskatchewan and Manitoba were investigated during the period 1984-1988. Mafic and ultramafic host rocks at each locality were examined for their potential to host economic concentrations of platinum-group elements (PGE), nickel-copper-cobalt and chrome mineralization as well as to document, characterize and date the various intrusions. In addition to investigating conventional environments, ie. mafic and ultramafic intrusions, unconventional geological environments as diverse as sedimentary and volcanic exhalative ores, hydrothermal Au mineralization and a meteorite impact site were also investigated.

A brief overview of some of the more important findings of this study will be discussed. Reference to locality and litho-structural domain can be made with the aid of Figure 1.

WESTERN CRATON

Clearwater Anorthosite Complex

The Clearwater Anorthosite Complex is a large, massif-type anorthosite complex in the Western Craton, and represents the second largest concentration of basic rocks in the province of Saskatchewan. The complex is shown on the 1:1,000,000 map of Saskatchewan as having an approximate strike length of 62 km and a width of 14 km (Macdonald and Broughton, 1980). However, field work conducted during this study demonstrates that the central portion of the complex is approximately twice as wide as previously suggested and is clearly one of the largest anorthosite complexes in Canada.

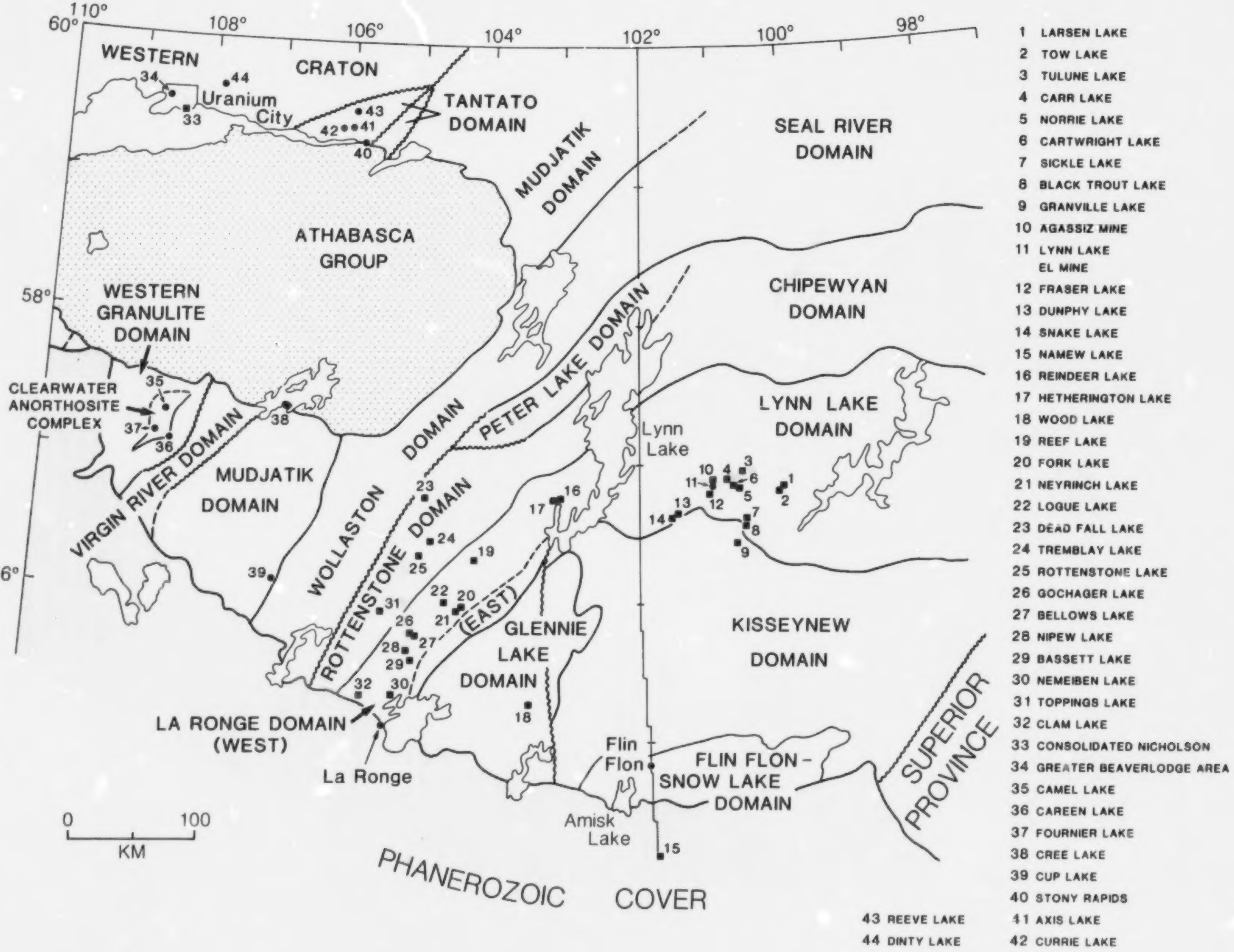
An east-west section from Fourier Lake to the Clearwater River disclosed that the complex consists of a well-layered cumulate sequence of anorthosite, noritic anorthosite, norite, gabbronorite, magnetite gabbro, magnetitite and felspathic pyroxenites. The strike of cumulate layering and the general trend of the complex is north-northeast. Samples containing fresh ortho- and clinopyroxene and plagioclase were sampled from areas retaining cumulate textural features. Nd-Sm age determinations on these samples indicate that the Clearwater Anorthosite Complex is 2.48 +/_ 0.03 Ga.

Compositional ranges (Mg numbers and An contents) for the fresh magmatic pyroxenes , olivines, and plagioclase minerals are as follows: opx, 0.42-0.79; cpx, 0.66-0.81; ol, 0.77; and pl, 0.38-0.68. Analyses of minerals from the Fourier Lake - Clearwater River traverse confirm field observations which suggest that the complex faces eastward. Establishment of the facing direction is very important and should be given serious consideration in future platinum-group element exploration.

Although this complex has all the characteristics of massif-type anorthosite intrusions (Gochnauer, 1978) it is unlike others in that it contains anomalous levels of sulphides. In the central portion of the complex, between Fournier Lake and the Clearwater River, numerous stratabound, and in one case, stratiform sulphide concentrations were discovered during this study. Pt, Pd and Au analyses indicate that mineralization from this portion of the layered sequence is barren in PGEs. The highest Pd, Pt and Au values are 3, <15 and 80 ppb respectively. The highest Au value (84 ppb) was found in a 10 cm thick magnetite layer.

Massive and semi-massive pyrrhotite-rich sulphides occur at Camel Lake and Careen Lake. This mineralization is confined to bronzitites, feldspathic bronzitites and norites and it is believed that these less fractionated intrusions represent early sill-like differentiates synchronous with the emplacement of the main Clearwater Anorthosite intrusion and that similar lithologies and mineralization could be expected at the base of the main complex. Analyses of this mineralization reveals that these sulphides also contain very low levels of Pd, Pt and Au (52, < 30 and 204 ppb respectively).

Although initial PGE prospecting results have been disappointing this large Archean to Early Proterozoic anorthosite complex should not be overlooked for future PGE, Ni-Cu and Fe-Ti-V exploration.


110°
108°
106°
104°
102°
100°
98°
60°
58°
56°
WESTERN CRATON
Uranium City
TANTATO DOMAIN
MUDJATIK DOMAIN
SEAL RIVER DOMAIN
ATHABASCA GROUP
CHIPEWYAN DOMAIN
WESTERN GRANULITE DOMAIN
CLEARWATER ANORTHOSITE COMPLEX
PETER LAKE DOMAIN
LYNN LAKE DOMAIN
Lynn Lake
VIRGIN RIVER DOMAIN
MUDJATIK DOMAIN
WOLLASTON DOMAIN
ROTTENSTONE DOMAIN
(EAST)
GLENNIE LAKE DOMAIN
KISSEYNEW DOMAIN
LA RONGE DOMAIN (WEST)
La Ronge
Flin Flon
FLIN FLON - SNOW LAKE DOMAIN
SUPERIOR PROVINCE
Amisk Lake
0
100
KM
PHANEROZOIC COVER
1 LARSEN LAKE
2 TOW LAKE
3 TULUNE LAKE
4 CARR LAKE
5 NORRIE LAKE
6 CARTWRIGHT LAKE
7 SICKLE LAKE
8 BLACK TROUT LAKE
9 GRANVILLE LAKE
10 AGASSIZ MINE
11 LYNN LAKE EL MINE
12 FRASER LAKE
13 DUNPHY LAKE
14 SNAKE LAKE
15 NAMEW LAKE
16 REINDEER LAKE
17 HETHERINGTON LAKE
18 WOOD LAKE
19 REEF LAKE
20 FORK LAKE
21 NEYRINCH LAKE
22 LOGUE LAKE
23 DEAD FALL LAKE
24 TREMBLAY LAKE
25 ROTTENSTONE LAKE
26 GOCHAGER LAKE
27 BELLOWS LAKE
28 NIPEW LAKE
29 BASSETT LAKE
30 NEMEIBEN LAKE
31 TOPPINGS LAKE
32 CLAM LAKE
33 CONSOLIDATED NICHOLSON
34 GREATER BEAVERLODGE AREA
35 CAMEL LAKE
36 CAREEN LAKE
37 FOURNIER LAKE
38 CREE LAKE
39 CUP LAKE
40 STONY RAPIDS
41 AXIS LAKE
42 CURRIE LAKE
43 REEVE LAKE
44 DINTY LAKE

Dinty Lake

The Dinty Lake Ni-Cu deposit is estimated to contain about 1,500,000 tons of pyrrhotite-rich sulphide mineralization containing up to 0.6 % nickel (Blake, 1955).

Examination of the host intrusion has revealed that it is not part of the extensive north shore "noritic series or suite" (Kranck, 1955) which extends from the mouth of the Fond-du-Lac River in the west to the Lytle Lake area east of Stoney Rapids. Field examination of this so-called "noritic" body (Blake, 1955) demonstrates that it was originally a layered intrusion consisting of anorthosite, anorthositic norite, feldspathic pyroxenite, pyroxenite and mineralized equivalents. Subsequent metamorphism to the granulite facies has given rise to garnetiferous equivalents in the more anorthositic differentiates.

The Dinty Lake mineralization differs from that of the north shore "noritic series" in that it occurs in anorthositic differentiates, has much lower nickel, copper and PGEs, and contains anomalous concentrations of molybdenite.

A Nd-Sm isochron constructed from fresh pyroxenes and feldspar separates extracted from the samples retaining primary cumulate looking textures suggest that this intrusion is 2.55 +/- 0.23 Ga.

THE NORTH SHORE NORITE-ORTHOPYROXENITE ASSOCIATION

Significant Ni-Cu-Co mineralization is present in noritic bodies that extend along the north shore of the Fond-du-Lac River. These intrusions are confined to the Tantato Domain which is bounded to the north by the Grease River Shear Zone and to the east by the Black Lake Shear Zone (Sask. Geol. Surv., 1987).

The most notable concentration of disseminated and massive Ni-Cu sulphides occurs at Currie Lake and Axis Lake (Colborne, 1960, 1962). Field examination indicates clearly that these differentiated and metamorphosed sills range in composition from norite to orthopyroxenite. A preferential concentration of massive sulphides and relict net-textured sulphides along the southern margin suggest a north-facing attitude. At Currie Lake a 7 m wide mineralized zone, averaging 1.02 5 % Ni, 0.22 % Cu with local values reaching 2.53 % Ni and 0.6 % Co (Colborne, 1962), have been discovered. Since thin, sill-like bodies can contain Ni-Cu-Co mineralization of the observed grade, the possibility of discovering commercial deposits of this type should be considered, in particular north of Stony Rapids where these rocks form an 8000 m thick series which occupies the centre of a large syncline (Colborne,1960).

MUDJATIK DOMAIN

Cup Lake

Numerous ultramafic intrusions are present in the Mudjatik Domain, including Dot Lake, Three Phase Lake, Centipede Lake, Porter lake, Splash lake, Bear Rapids and Cup Lake. The Cup Lake Ultramafic Complex is the largest known ultramafic body in the Mudjatik Domain and was the focus for characterizing mafic-ultramafic intrusions in the Mudjatik lithostructural domain. Detailed field and laboratory investigations disclosed that the Cup Lake intrusion is a layered, sill-like body consisting of orthopyroxenite, websterite, harzburgite and minor dunite and has been metamorphosed to granulite facies conditions. The orthopyroxenes, clinopyroxenes and olivines have Mg numbers of 0.82, 0.87-0.92 and 0.80-0.86 respectively suggesting that the parent magma to these intrusions was basaltic and not komatiitic in composition. The high nickel content of the olivine (0.28-0.34 wt. percent NiO) suggests that this intrusion is unlikely to host commercial concentrations of Ni-Cu sulphides. The low PGE values obtained from mineralized and unmineralized material from this intrusion also suggest that it is a poor candidate for economic concentrations of PGE.

ROTTENSTONE DOMAIN

Rottenstone deposit

Investigations conducted on the Hall and Tremblay-Olson mineralization at Rottenstone Lake, Saskatchewan clearly demonstrated marked geochemical and mineralogical differences between intrusions enriched in PGE and those poor in PGE. Nickel-copper sulphide mineralization in the PGE-enriched Hall deposit has high selenium and tellurium concentrations and corresponding low S/Se ratio (<4500) relative to the PGE-poor Tremblay-Olson showing. Also, the presence of disseminated graphite in the Hall mineralization and its absence at the Tremblay-Olson showing suggests that PGE enriched sulphides are favored by magmas having reduced oxidation states. Carbon-isotope analyses of the graphite suggests that Rottenstone graphite is similar to that encountered in other PGE-enriched intrusions, ie. Bushveld and Stillwater Complexes. The above mentioned criteria distinguishing PGE-enriched from PGE-poor mineralization at Rottenstone Lake can also be applied to other intrusions hosting Ni-Cu sulphide mineralization in the Trans-Hudson Orogen of Saskatchewan and Manitoba.

Detailed chemical analyses of the chromite phases also disclosed marked differences between the two localities. Chromite from the Hall showing is zinc- and aluminum-rich relative to the Tremblay-Olson chromite. This, in conjunction with the sulphur- and carbon-isotope analyses, clearly demonstrates contamination of these magamas by different source rocks. In the case of the Hall deposit this sulphur-enriched source rock was also enriched in selenium and tellurium. It is inferred that assimilation of selenium- and/or tellurium- enriched crustal rocks enhances the scavenging capability of immiscible sulphides in the melt regardless of the initial basaltic concentration of PGE in the melt. These results suggests that future PGE exploration should be focused on terranes known to contain country rock sulphides enriched in Se and Te.

LaRONGE DOMAIN

The greatest number of mafic-ultramafic intrusions and associated Ni-Cu mineralization occurs in this domain. One of the bodies, the Lynn Lake intrusion, was in production for 25 years and for the size of the host mafic-ultramafic body it was probably the most productive intrusion in the history of nickel mining in North America.

Nd-Sm isotopic systematics for six intrusions from this domain indicate crystallization ages between 1.88 and 1.79 Ga. This, in conjunction with detailed field and laboratory examinations, indicate distinct intrusive events at 1.88, 1.81 and 1.79 Ga (Hegner et al., 1989).

The mafic-ultramafic intrusions are either plug-like or sill-like in form and generally have an internal layering. It appears that only intrusions with a plug-like form contain significant amounts of Ni-Cu sulphides. The largest concentration of these mineralized plug-like intrusions occurs in the southern portion of the domain (Nemeiben, Clam, Reef, Gochager and Bassett Lakes intrusions) (Figure 1). In general these intrusions have a higher proportion of ultramafic cumulates with more primitive mafic phase chemistry and a narrower differentiation range (Mg number; ol, 0.86-0.67, opx, 0.88-0.69, cpx, 0.90-0.69) than that encountered in the northern Manitoba portion of this domain. There appears to be fewer mafic-ultramafic intrusions in the central portion of this domain.

In contrast most of the intrusions in the northern part of the domain occur within a 40 km radius of Lynn Lake. The majority of these intrusions are sills or their deformed equivalents. The grade of superimpossed metamorphism increases southwards from the Tow Lake-Lynn Lake area towards the Saskatchewan border. Most of these sill-like bodies are 1.88 +/- 0.04 Ga and are contemporaneous, but not comagmatic, with the surrounding basaltic volcanics which they intrude and assimilate. Detailed chemical and mineralogical studies demonstrate that most of these bodies are moderately to extensively fractionated :

Tow Lake;	pl,	$An_{62-37.5}$
	cpx, Mg#=	0.75-0.15
	opx,	0.67-0.36
	ol,	0.46-0.44
Cartwright Lake;	pl,	An_{78-49}
	cpx,	0.81-0.70
	opx,	0.74-0.58
	ol,	0.74-0.67
Lynn Lake;	pl,	An_{72-42}
1.88 Ga body	cpx,	0.78-0.75
	opx,	0.74-0.72
1.79 Ga body	pl,	An_{81-79}
	ol,	0.86-0.81
	cpx,	0.83-0.81
	opx,	0.82-0.79

Fraser Lake	pl,	$An_{89.6-54.2}$
Layered	ol,	0.77-0.58
Series	cpx,	0.76-0.68
1.88 Ga	opx,	0.75-0.60
S.E. Lobe	pl,	$An_{75.5}$
1.79 Ga Body	cpx,	0.81
	opx,	0.81-0.79

The Ni-Cu mineralization associated with this domain is characteristically depleted in PGE relative to other terranes in Canada. The reason for this pronounced depletion may be that the PGE content of the contemporaneous volcanics were found to be higher than that of the the cumulate-bearing intrusions. It is inferred that the partial melting event which gave rise to this extensive volcanic "Greenstone" terrane depleted that portion of the mantle in PGE. Subsequent partial melting, which gave rise to the nearly contemporaneous mafic-ultramafic intrusive event, took place in a PGE-depleted environment. Therefore, significant PGE concentrations could not be developed in the sulphides because of the depleted nature of the parental magma.

The only significant PGE mineralization encountered in the LaRonge-Lynn Lake domain is that associated with a hydrothermal environment in the Nemeiben Lake intrusion. Localized high platinum and palladium values (0.126 oz/ton combined Pt and Pd over 1.7 m) were discovered in a fractured and extensively hematized dunite that has subsequently been infilled with pyrite and chalcopyrite.

Basic to intermediate intrusions of a calc-alkaline parentage are also present within this domain. This type of intrusion is distinct from the other tholeiitic intrusions in terms of their chemistry, mineralogy, macroscopic appearance and PGE content. The Neyrinck Lake intrusion, and the Carr Lake intrusion (250 km to the northeast) (Figure 1), are of this calc-alkaline parentage. Nd-Sm isotopic systematics determined in this study have established an age of 1.81 +/- 0.06 Ga for the Neyrinck Lake intrusion. U-Pb ages from zircons of the Star Lake pluton, 2.5 km northwest of the Neyrinck Lake intrusion, gave an age of 1.848 +/- 0.014 Ga (Van Schmus et al., 1987). The near proximity, similar age, calc-alkaline parentage, the presence of comagmatic gabbroic rocks in the Star Lake pluton and the gold-rich nature of the Cu-sulphide mineralization suggest that the Star Lake and Neyrinck Lake plutons may be coeval. It is also interesting to note that the sulphide mineralization at Neyrinck Lake contains the highest magmatic PGE concentrations in the domain relative to the sulphide content.

GLENNIE LAKE DOMAIN

Wood Lake (Daniel-Tri Lake)

The largest mafic-ultramafic complex and best Ni-Cu mineralization in the Glennie Lake domain occurs in the Daniel - Tri lakes area, 7 km west of Wood Lake, Saskatchewan.

Nd-Sm isotopic systematics indicate a crystallization age of 1.71 +/- 0.05 Ga. Apart from the Mackenzie diabase event, this age establishes the Wood Lake intrusive event as the youngest period of basic magmatism in the Trans-Hudson Orogen in northern Saskatchewan, a fact that was not previously appreciated.

Electron microprobe analyses reveal that the cumulate sequence in this intrusion has a limited differentiation range. The Mg number of the olivine, clinopyroxene and orthopyroxene range from 0.80-0.73, 0.88-0.79 and 0.82-0.74, respectively. The associated Ni-Cu mineralization appears to be an immiscible magmatic segregation product occurring near the base of the intrusion. Analyses indicate that this mineralization is also depleted in PGE's, similar to that of the LaRonge-Lynn Lake Domain.

PETER LAKE DOMAIN

Peter Lake Complex

The Peter Lake Complex is the largest concentration of mafic rocks in Saskatchewan and, after the Duluth Complex, it is the second largest mafic intrusion complex in North America. The main mass of the complex is made up of a suite of plutonic rocks ranging in composition from gabbro to diorite with minor ultramafic and anorthositic components. It is approximately 200 km long, and has a width of 25 to 30 km. The complex may be a product of rift related magmatism during late Archean times, analogous to the late Proterozoic rift related magmatism that gave rise to the Duluth Complex.

As a result of the present program of research carried out on this complex, exploration for PGE's was initiated by industry, and lead to the discovery of two different styles of mineralization. The older type is low-grade, magmatic Cu-

Ni mineralization that occurs sporadically along the eastern margin. Much later hydrothermal mineralization is associated with the northerly trending Tabbernor Lake fault system. This hydrothermal mineralization is much higher grade than the magmatic type. Both types of mineralization occur at Ant Lake, 4.2 km west of Patterson Island, Reindeer Lake. At this locality PGE's in disseminated magmatic mineralization seldom exceeds 300 ppb Pt + Pd, whereas values as high as 5162 ppb Pt + Pd have been found associated with the hydrothermal type. The immense size of this complex and the presence of significant PGE mineralization suggest that the Peter Lake Complex has substantial PGE potential, and also that these elements can be transported in a hydrothermal environment.

MACKENZIE DIABASE DYKES AND SILLS

The middle Proterozoic Mackenzie igneous event is one of the most widespread episodes of basic magmatism to occur in the continental crust. It produced the Coppermine River flood basalts, the Muskox intrusion and the extensive dyke swarm and related sills. A significant volume of these dykes and sills occur in north central and western portions of the Trans-Hudson Orogen in Saskatchewan. The most extensive research ever conducted on these intrusions in Saskatchewan took place under the present Mineral Develpment Agreement. As a result, it is clear that these intrusions represent more than just an incidental period of basic dyke activity in the geological history of the Precambrian of northern Saskatchewan. U-Pb dating of baddeleyite from these intrusions has given a precise age of 1265 +/- 2 Ma. This age corresponds very well with the best age estimates (Wallis et al., 1983) for the unconformity-type uranium mineralization in northern Saskatchewan. The coeval nature of the Mackenzie basic intrusive period and one of the worlds largest uranium metallogenic events strongly suggests that this magmatic activity is a prime candidate for the regional heat source that drove the uranium-bearing hydrothermal systems alluded to by Hoeve and Sibbald (1978).

Apart from being precise time markers in the Precambrian shield of northern Saskatchewan, and the heat source for the hydrothermal systems that gave rise to the uranium deposits, these bodies have significant Cu-Ni-PGE potential. Detailed investigation of sill-like bodies at Tremblay Lake and Dead Fall Lake (6.4 km southeast of Howe Lake) has demonstrated that these intrusions are considerably enriched in Pt, Pd and Au relative to other magmas of a basaltic parentage. Unmineralized samples (<250 ppm sulphur) from these sills were found to contain the following levels of Pd, Pt and Au:

	Pd(ppb)	Pt(ppb)	Au(ppb)
Tremblay Lake			
Mean=	36.8	7.5	6.5
No. of Samples=	32	32	32
Max. Value=	125	37	14
Min. Value=	10	2	1
Variance=	752	40.5	7.8
Std. Dev.=	27.4	6.3	2.8
Deadfall Lake			
Mean=	29.6	7.9	8.7
No. of Samples=	33	33	33
Max. Value=	75	43	27
Min. Value=	2	1	1
Variance=	129.5	59.6	19.6
Std. Dev.	11.4	7.7	4.4

Subsequent to these analyses, significant Cu-Ni-PGE mineralization has been discovered in the Muskox intrusion. There is clear evidence that the Muskox mineralization formed in response to contamination of the magma by crustal sulphur. Generation of similar immiscible sulpides in the diabase intrusions of northern Saskatchewan has to be given serious consideration. It would appear from the geology and the geochemical database established during this study that those bodies intruding the Athabasca Formation would be the best candidates. It is interesting to note that diabase samples collected from within the Athabasca Formation are enriched in copper relative to those outside.

GREATER BEAVERLODGE AREA

U-Au-PGE Association

Significant levels of (PGE) mineralization were discovered in the Greater Beaverlodge mining camp along with uranium over forty years ago. Until recently, the presence of the PGE mineralization has been treated as a mere geological curiosity. Research conducted on this unconventional PGE association helped bring to the attention of the exploration community (Hulbert, 1987; Hulbert et al., 1988 a & b; Hulbert et al, 1989) that significant PGE mineralization can be found in association with uranium mineralization. The Nicholson-Fish Hook Bay area of the Greater Beaverlodge Mining camp should be considered the type area for the unconformity-related U-Au-PGE association.

Our studies have shown that the uranium, gold and platinum-group element mineralization is confined to extensively fractured, carbonate-infilled and hematized Proterozoic calcareous and psammitic metasediments. Studies in the Nicholson Bay area revealed that anomalous levels of PGE are found only where uranium-bearing fracture zone occur in the immediate vicinity of peridotite. In areas where no surface expression of ultramafic rocks is present anomalous chrome concentrations clearly point to a mafic-ultramafic source for the PGE.

Detailed geochemical and mineralogical studies have shown that Se, Bi, Sb and Uranium are important pathfinder elements. Approximately fifty percent of the metallic phases identified in this study are selenides, and along with Sb and Bi-minerals constitute the primary platinum group minerals. Gold and Au-Pd and Au-Ag-Pd alloys are also important hosts for PGE.

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CHARACTERIZATION OF MAFIC-ULTRAMAFIC INTRUSIVE ROCKS IN THE FLIN FLON-SNOW LAK AREA, MANITOBA

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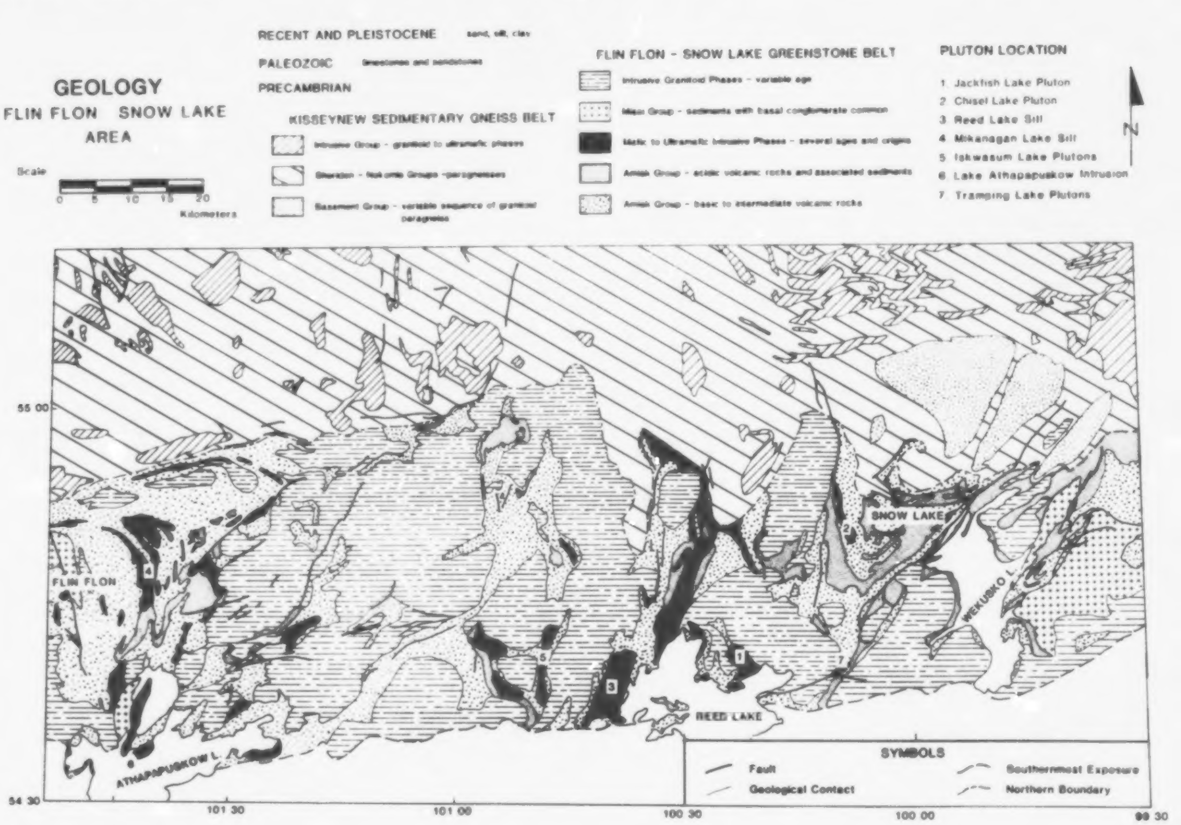
Mafic and ultramafic plutonic rocks, as either discrete plutons or components of more felsic plutons, are volumetrically minor constituent of many geologic terranes. Some of these plutons contain exploitable deposits o nickel, copper, platinum group elements, chromium, titanium, vanadium, and cobalt, but the distribution, and controls o the distribution of economically important elements, particularly platinum group elements, are poorly documented. I order to evaluate the economic potential of such plutons in Manitoba, we have investigated the basic geology ar geochemistry, tectonic setting, and nature of known mineralization of 12 mafic-ultramafic plutons and pluton groups i the Early Proterozoic Flin Flon-Snow Lake greenstone belt (Table 1; Figure 1). The recent discovery of nickel-coppe mineralization in one such pluton, at Namew Lake, in gneisses marginal to the greenstone belt, and of concentrations o platinum group elements in the Archean Bird River and Proterozoic Fox River belts of Manitoba highlights the importanc of this investigation.


GEOLOGY
FLIN FLON SNOW LAKE AREA
Scale
0 5 10 15 20
Kilometers
RECENT AND PLEISTOCENE sand, silt, clay
PALEOZOIC limestones and sandstones
PRECAMBRIAN
KISSEYNEW SEDIMENTARY GNEISS BELT
Intrusive Group - granitoid to ultramafic phases
Sherridon - Nokomis Groups - paragneisses
Basement Group - variable sequence of granitoid paragneiss
FLIN FLON - SNOW LAKE GREENSTONE BELT
Intrusive Granitoid Phases - variable age
Missi Group - sediments with basal conglomerate common
Mafic to Ultramafic Intrusive Phases - several ages and origins
Amisk Group - acidic volcanic rocks and associated sediments
Amisk Group - basic to intermediate volcanic rocks
PLUTON LOCATION
1 Jackfish Lake Pluton
2 Chisel Lake Pluton
3 Reed Lake Sill
4 Mikanagan Lake Sill
5 Iskwasum Lake Plutons
6 Lake Athapapuskow Intrusion
7 Tramping Lake Plutons
N
55 00
54 30
101 30
101 00
100 30
100 00
99 30
FLIN FLON
SNOW LAKE
REED LAKE
WEKUSKO L.
ATHAPAPUSKOW L.
1
2
3
4
5
6
SYMBOLS
Fault
Geological Contact
Southernmost Exposure
Northern Boundary

1. Geology of the Flin Flon-Snow Lake greenstone belt (modified from Bailes, 1971), showing the location of examined mafic-ultramafic plutons.

Table 1. Characteristics of examined mafic-ultramafic plutons, Flin Flon-Snow Lake greenstone belt.

Pluton	Habit and dimensions	Lithology	Internal structure	Mineralization	Comments
SUBVOLCANIC PLUTONS					
Reed Lake Pluton	concordant, plug-like body, now subvertical and east-facing; 10 km long and 4 km thick	largely metagabbro with some metaperidotite, pyroxenite, and meta-anorthosite in lower part	megalayers and cyclic units, some of which have well developed, thin to thick, in part modally graded layers; local metavolcanic septa separating megalayers and cyclic units	minor disseminated pyrite and chalcopyrite in ultramafic layers; minor chromite concentrations in some layers	compositional variation controlled by multiple intrusion and fractionation; may be structurally controlled by a volcanic edifice
Lower Grass River Pluton (Iskwasum area)	concordant sill now subvertical and northeast-facing; broadly warped around granitoid plutons; mapped length of 6 km but ends not defined; 150-1000 m thick; disrupted by post-solidification faults	40% serpentinized and steatitized peridotite, and metapyroxenite; 60% metagabbro	generally a discontinuous basal metagabbro zone, lower ultramafic zone, and upper metagabbro zone; in places ultramafic and metagabbro zones are repeated and partly separated by metavolcanic septa; thin to thick layers, rhythmic laminae, and trough layers locally observed	local pyrite concentrations in metagabbro, in part associated with quartz veins; talc-rich areas common	probably a multiple intrusion; compositional variations largely due to fractionation
Upper Grass River Pluton (Iskwasum area)	concordant body now subvertical and northeast-facing; at least 2.5 km long and 900 m thick but ends and upper contact not defined	largely melametagabbro to leucometagabbro with minor serpentinized peridotite metapyroxenite, and meta-anorthosite	discontinuous ultramafic zone <45 m thick that is in part cyclic and has well developed, thin to thick layers; metagabbro varies from well layered, with discontinuous laminae to thick layers, to heterogeneous	no known sulphide mineralization; minor disseminated Fe-Ti oxides and chromite	separated from Lower Grass River Pluton by 120-500 m thick metavolcanic septum
Barb Lake Pluton (Iskwasum area)	apparently concordant sill that is now subvertical and east-facing; 10.5 km long but north part truncated by granitoid pluton; up to 1.5 km thick	largely metagabbro with some serpentinized peridotite, metapyroxenite, and meta-anorthosite	lenticular ultramafic zones in lower part of pluton; metagabbro is heterogeneous with irregular patches defined by variations in grain size and mineral proportions; local, isolated, thin to thick, ungraded layers in metagabbro; one internal metavolcanic septum	localized concentrations of pyrite and pyrrhotite are best developed in ultramafic zones	
Iskwasum Lake Pluton	concordant sill that is now subvertical and northeast-facing; 8 km long with maximum thickness of 1.4 km; disrupted by post-solidification faults; lower and eastern parts largely covered by lake	40% serpentinized and steatitized dunite and peridotite, and metapyroxenite; 60% metagabbro and leucometagabbro	a lower ultramafic zone and upper metagabbro zone; in places, this is overlain by a second cycle comprising lower ultramafic rocks and upper metagabbro; the two cycles are separated by a discontinuous metavolcanic septum; proportion of ultramafic rocks is lower in upper cycle than in lower cycle; ultramafic zones are thickly layered but layering largely obscured by variable serpentinization; metagabbro is heterogeneous with patches and layers defined by variations in mineral proportions and size	disseminated pyrite, pyrrhotite, and rare chalcopyrite in ultramafic rocks of lower cycle; talc-rich zones common; some asbestos; rare chromite in ultramafic rocks.	multiple intrusion with two major influxes of magma; compositional variations due to fractionation, and, in metagabbro, to magma movement
Athapapuskow Lake Sill	concordant sill that is now subvertical and faces south-southeast; 15 km long with maximum width of 800 m; exposed only on scattered islands	oxide-rich metagabbro; no ultramafic rocks observed	none although mineral proportions and sizes vary from place to place; local quartz-rich zones represent residual concentrations of iron-rich magma	Fe-Ti oxide concentrations; rare disseminated pyrite and pyrrhotite	probably a multiple intrusion of iron-rich magma; limited post-emplacement fractionation
HIGH-LEVEL PLUTONS					
Mikanagan Lake Sill	concordant sill that is now subvertical and east-facing; 14 km long with maximum thickness of 1.2 km	metagabbro, quartz metadiorite, metatonalite, and rare meta-anorthosite; no ultramafic rocks observed	mineralogical and textural variations define 7-8 mappable zones; progressive upward compositional change from metagabbro at base to metatonalite at top; thin discontinuous metavolcanic septum near centre of sill has only limited affect on compositional variations; thin to medium layers locally present in lower part of sill but not observed in upper part	disseminated sulphide minerals and Fe-Ti oxide concentrations in upper part of metagabbro near centre of sill	only north part of sill examined; south part mapped by Bailes and Syme (1987); possible multiple intrusion with extensive fractionation

Pluton	Habit and dimensions	Lithology	Internal structure	Mineralization	Comments
SYNTECTONIC PLUTONS					
Jackfish Lake Pluton	rectangular stock 2.5 by 5 km; generally bounded by younger granitoid rocks of Reed Lake Batholith, but locally in intrusive contact with older mafic metavolcanics	largely gabbro but some troctolite, pyroxenite(?), norite, quartz gabbro, and anorthosite	crudely zoned with clinopyroxene/plagioclase increasing outward; at least 25 phases, defined by textural and mineralogical variations, vary from xenoliths through dykes and layers to irregular patches; layering only rarely observed; numerous metavolcanic xenoliths; recrystallized adjacent to Reed Lake Batholith	19 known zones of 0.5-10% pyrite-pyrrhotite-chalcopyrite; sulphide minerals generally interstitial to silicate minerals in gabbro or norite, but spatially associated with country rock xenoliths; assay values of >1% Cu or >1% Ni recorded from narrow zones	early phase of Reed Lake Batholith; piecemeal emplacement from a fractionating, deeper chamber
Tramping Lake Plutons	three, lenticular to oval units within, or at the margins of the Reed Lake and Tramping Lake granitoid batholiths; range in length from 1-3 km and in width from 0.3-1.1 km; partly covered by lake	metagabbro, in part anorthositic, and metadiorite; rare metapyroxenite xenoliths	multiphase plutons with phases defined by variations in mineral abundance and texture; up to 5% metavolcanic and metasedimentary xenoliths; no layering observed	rare disseminated pyrite; local concentrations of Fe-Ti oxides	although metamorphosed, the degree of recrystallization is less than in subvolcanic or high-level plutons adjacent to younger granitoids; probably early phases of post-Amisk but pre-Missi granitoid batholiths
LATE TECTONIC PLUTONS					
Chisel Lake Pluton	probably a folded sheet which now has an upright, canoe shape with a teardrop-like outline, 9.8 km long; maximum width is 1.8 km; discordant to adjacent metavolcanic-metasedimentary strata	50% metaperidotite and metapyroxenite; 50% metagabbro; minor gabbroic meta-anorthosite in layers and xenoliths	thin marginal metagabbro is overlain, in turn, by a thick metaperidotite zone, a thin metapyroxenite zone, and 3 metagabbro zones; quartz content increases upward through the metagabbro; some zones are asymmetric, and not all zones extend the length of the pluton; at the north end, there are 2 ultramafic-mafic cyles separated by a metavolcanic septum; several large metavolcanic blocks occur in axial zone of pluton; modal layering is confined to uppermost metaperidotite, metapyroxenite, and lowermost metagabbro; layers vary from continuous to discontinuous, and planar to cross-stratified to scoured; layer convolution common; igneous lamination well developed in lower part of metagabbro	widespread, but sparse, disseminated pyrite and pyrite veinlets; rare chalcopyrite in veinlets in lower part of metaperidotite zone; local concentrations of chromite and Fe-Ti oxides; truncates Chisel Lake Cu-Zn orebody in country rocks	multiple intrusion comprising 2 major, and numerous smaller magma batches; internal fractionation was coupled with downsagging of the chamber floor, addition of magma batches, and magmatic currents; cumulus sequence was olivine-oxides-orthopyroxene-clinopyroxene-plagioclase
Athapapuskow Lake Stock	tadpole shaped stock largely covered by lake; 4 km long and 2 km wide; discordant pluton but tilted so that top now faces southeast; possibly related to unexamined ultramafic body to north-northwest (Syme, 1988)	pyroxenite, hornblende pyroxenite, and gabbronorite in exposures; possible peridotite beneath lake; ultramafic rocks appear to predominate	appears to have gabbro rim, inside of which there is an upward progression from pyroxenite to gabbronorite; peridotite may occur beneath pyroxenite in area covered by lake; poorly exposed, thin to thick layers in pyroxenite defined by modal and grain size variations	pyrite + pyrrhotite in veinlets; asbestiform cummingtonite and serpentine veinlets	possibly emplaced along a fault

The plutons are tholeiitic and range in composition from dunite to tonalite, but the variety and proportions of lithologies differ from pluton to pluton. They have been provisionally classified into four tectonic groups (Table 1): 1) subvolcanic sills, stocks, and plugs within mafic to intermediate metavolcanic rocks to which they appear to be genetically related (6 plutons); 2) high-level sills within metasedimentary and felsic to intermediate metavolcanic sequences that normally overlie thick mafic metavolcanic sequences (1 pluton); they may be contemporaneous with volcanism, but their stratigraphic position would then imply a second period of mafic magmatism, which either did not broach the surface, or the volcanic products of which have been largely eroded; 3) syntectonic stocks and zones that are spatially associated with, and appear to be early phases of, large granitoid batholithic complexes (2 plutons); and 4) late tectonic stocks and sheets (3 plutons). The various groups appear to represent a progressive evolution in the generation and upward movement of basaltic magma in response to crustal thickening and changes in crust-mantle conditions. The habit, size, and crystallization history of the plutons, in part, reflect these changing conditions.

Subvolcanic and high-level plutons are the most common type of mafic-ultramafic plutons in this and other greenstone belts. Many of these are sill-like bodies with an aspect ratio greater than 5, but the Reed Lake pluton is anomalous in terms of both low aspect ratio and great thickness (Table 1). Both types of plutons were deformed and metamorphosed with the enclosing metavolcanic-metasedimentary sequences. Consequently they now have subvertical dips, with the present exposure being a cross-section through the original pluton, and, in some plutons, the continuity of compositional zones is disrupted by faults. Primary mineral phases are commonly pseudomorphed by secondary phases, although magmatic pyroxenes are preserved in ultramafic zones of the Reed Lake and Iskwasum Lake plutons and locally in metagabbro of other plutons. Magmatic textures and structures are generally well preserved by the pseudomorphs.

Most subvolcanic plutons appear to represent multiple injections of tholeiitic or iron-rich tholeiitic gabbro magma into chambers in volcanic edifices, but the volume, timing, and composition of the new magma batches differed from pluton to pluton. Some magma batches were apparently derived directly from the mantle, whereas others had partly evolved in deeper chambers. Some plutons are strongly fractionated with a lower dunite-peridotite-pyroxenite zone forming as much as half of the pluton, overlain by gabbro; others are largely or entirely gabbro with limited internal compositional variation. Injection of new magma batches produced repeated cyclic compositional changes that range in thickness from a few tens of metres, such as in the Reed Lake Pluton, to those forming about half of the pluton as in the Iskwasum area. Internal, modally graded and ungraded layers were observed in the ultramafic and mafic zones of all plutons, but layering is commonly obscured by moss- and lichen-cover and by metamorphism. In the gabbro zones of some plutons, textural and mineralogical variations have a patchy distribution; this may reflect magma movement and injection into partly consolidated gabbro.

The only high-level pluton examined, the strongly fractionated Mikanagan Lake Sill, also appears to be a multiple intrusion, but it differs markedly in composition from subvolcanic plutons. Ultramafic phases are apparently absent, and the upward compositional change is from gabbro to tonalite; tonalite forms as much as 20% of the pluton volume. The high abundance of quartz-rich felsic rocks relative to typical, fractionated tholeiitic gabbro plutons may reflect pluton emplacement in, and assimilation of, felsic host rocks and/or more extensive fractionation of magma batches in deeper, more stable, magma chambers prior to ascent and emplacement in the high-level chamber.

Syntectonic plutons are multiphase gabbro-diorite bodies that occur between metavolcanic-metasedimentary country rocks and younger granitoid batholiths; ultramafic phases are restricted to sparse pyroxenite xenoliths. In the central part of the Jackfish Lake Pluton, olivine-rich troctolite and orthopyroxene-rich norite are minor phases. Unlike other pluton types, phases commonly have an irregular distribution, although in some plutons this is superimposed on a crude concentric zoning. The plutons are variably deformed and metamorphosed, but to a lower degree than subvolcanic or high-level plutons that occur adjacent to large granitoid batholiths. Primary mineral phases are partly to largely preserved; internal layering is rare. Contacts with the batholiths are commonly sharp, and the plutons are apparently early phases of the granitoid batholiths; deformation and metamorphism were produced by emplacement and rise of granitoid magmas.

Late-tectonic plutons are less deformed and metamorphosed than country rocks, but the degree of deformation and metamorphism varies from pluton to pluton, apparently as a function of metamorphic grade of country rocks. Although not included in Table 1, the late tectonic group apparently includes the Namew Lake pluton, host of a large Ni-Cu deposit. No post-tectonic plutons were examined; such plutons elsewhere are generally undeformed and unmetamorphosed although they may be altered to varying degrees.

The two examined, late tectonic plutons are strongly fractionated and, in places, have well developed layering. They range in composition from peridotite to gabbro and possibly diorite; ultramafic rocks are major components. Primary mineral phases are well preserved in the Athapapuskow Lake Stock but have been largely overprinted by low grade metamorphic assemblages in the Chisel Lake Pluton. The higher grade metamorphism of the Chisel Lake Pluton apparently reflects emplacement at a deeper crustal level where country rocks were still hot from the regional metamorphic event. Only the Chisel Lake Pluton is moderately well exposed, and it shows evidence of multiple emplacement of both small and large magma batches, magmatic currents that are partly related to magma injection and subsidence of the chamber floor, sinking of blocks from the roof, and fractionation.

The occurrence of mineralization in mafic-ultramafic plutons is the result of magmatic and tectonic processes, and it is probably a function of numerous interrelated factors including pluton habit, size, magma composition and emplacement, crystallization history and site, addition to and subtraction of magma from the chamber, and tectonic setting. In the examined plutons, extensive mineralization has been found only in the syntectonic Jackfish Lake Stock

(Table 1). This Cu-Ni mineralization is spatially, and possibly genetically related to abundant metavolcanic-metasedimentary xenoliths within the pluton.

In the other plutons, sulphide minerals are restricted to sparsely disseminated pyrite, and rare pyrrhotite and chalcopyrite, and to locallized thin veinlets containing pyrite and minor pyrrhotite and chalcopyrite. Disseminated chromite is a common constituent of peridotite in many plutons, and in the Chisel Lake Pluton, layers in the upper part of the ultramafic zone contain up to 10% chromite. Fe-Ti oxides are a ubiquitous constituent of gabbro, and in some plutons the oxide content is greater than 10%.

Although concentrations of platinum group elements have not been reported from the plutons examined, studies of platinum-bearing plutons elsewhere indicate that the most favourable plutons are large volume plutons produced by repeated injections of new, olivine-rich magma into the chamber (Campbell et al., 1983); such plutons are characterized by cyclic repetition of units. Platinum group elements generally occur in disseminated sulphide minerals at or near the base of cycles that are marked by the reappearance of cumulus olivine and chromite and that developed after the first appearance of cumulus plagioclase in the chamber; chromite concentrations are common in these cycles. Among the examined plutons, we consider the Reed Lake Pluton to be the most favourable prospecting target for platinum group elements. It contains a number of cyclic units that show an upward compositional change from peridotite or olivine pyroxenite to leucogabbro; several of the ultramafic layers are enriched in chromite, and disseminated sulphides have been observed in several cyclic units. In the other plutons, cyclicity in the critical lower part of gabbro zones appears to be poorly developed, although it has been observed in the upper Grass River Pluton, and possibly occurs in the Barb Lake Pluton. These two plutons, and the repeated ultramafic zones in the Iskwasum Lake, Lower Grass River, and north part of Chisel Lake plutons are also potential exploration targets.

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STRATIGRAPHY OF THE BIRD RIVER SILL AND ITS CHROMITIFEROUS ZONE, AND PRELIMINARY GEOCHEMISTRY OF THE CHROMITITE LAYERS AND PGE-BEARING UNITS, CHROME PROPERTY, MANITOBA

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INTRODUCTION

The Bird River Sill, a differentiated ultramafic to mafic layered intrusion of Archean age in southeastern Manitoba is well known as the repository of Canada's most significant chromite resource. Also associated with the Sill are nickel-copper sulphide deposits of which the most important are the Dumbarton and Maskwa West mines, both past producers of nickel and copper. In addition, anomalous values of platinum and palladium have recently been discovered in the sill.

The present study of the geology and metallogeny of the Bird River Sill on the Chrome Property was undertaken for a combination of reasons:

1. First, a detailed geological map of the stratigraphy and structure of the chromitite layers had not previously been prepared. Such a map would facilitate evaluation and potential development of the chromite deposits, as well as provide better understanding of their genesis.

2. The preservation and exposure of the chromitite layers on the Chrome Property is excellent, probably among the best in the world.

3. The Chrome Property also affords the best exposure of the entire stratigraphy of the Bird River Sill, at its thickest point.

4. The discovery in 1984 of anomalous levels of Platinum Group elements (PGE) in the Sill on the Chrome property made it imperative to investigate the nature, extent and controls of this new type of mineralization.

Consequently the MDA project that was proposed in 1985 to carry out studies of the Bird River Sill/Chrome Property had for its objectives "to document the nature, distribution and origin of chromitite layers and subeconomic concentrations of platinum-group element-bearing rocks in the Ultramafic Series of the Bird River Sill. Detailed maps, at a variety of scales, will illustrate significant elements of the stratigraphy of the sill."

The present report summarizes results achieved, under the following headings:

I. Stratigraphy of the Bird River Sill and the contained chromitites and PGE-bearing units.

II. Geochemistry of the PGE mineralization

III. Composition of chromite.

GENERAL GEOLOGY

The Bird River Sill is exposed discontinuously along both limbs of an eastward plunging anticline, the core of which is occupied by the Maskwa Lake Batholith (Figure 1). The sill has a strike length of at least 25 km along the south limb, and is exposed over a strike length of 4 km in two widely separated localities along the north limb of the structure. The exposed width rarely exceeds 600 m and, since the dip is commonly near vertical, this reflects the true thickness of the body.

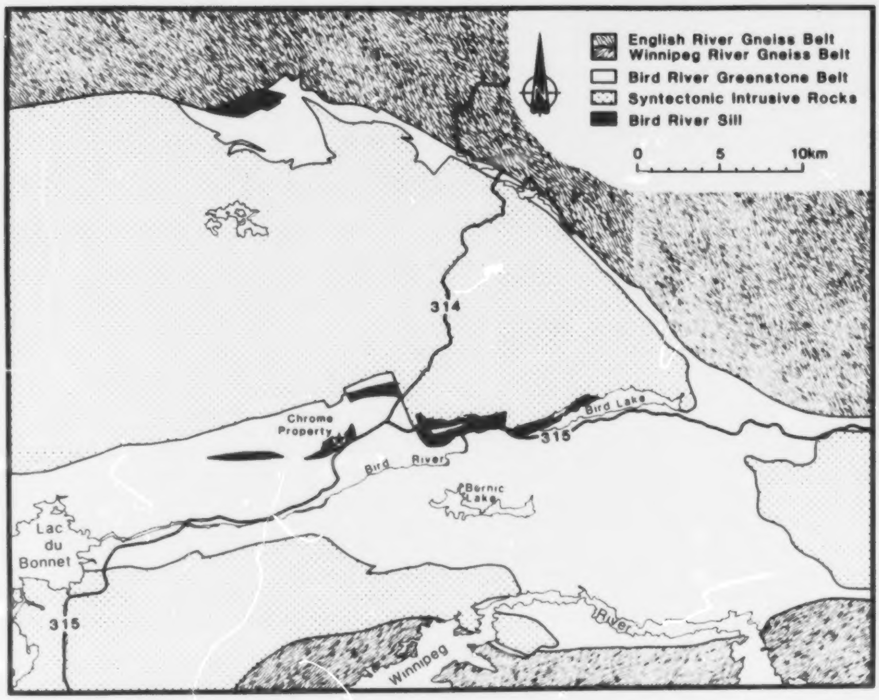
English River Gneiss Belt
Winnipeg River Gneiss Belt
Bird River Greenstone Belt
Syntectonic Intrusive Rocks
Bird River Sill
0
5
10km
314
Chrome Property
Bird River
Bird Lake
315
Bernic Lake
Lac du Bonnet
315
Winnipeg
River

Figure 1. Generalized geology of the Bird River greenstone belt, southeastern Manitoba, showing the disposition of the Bird River Sill and the location of the Chrome Property.

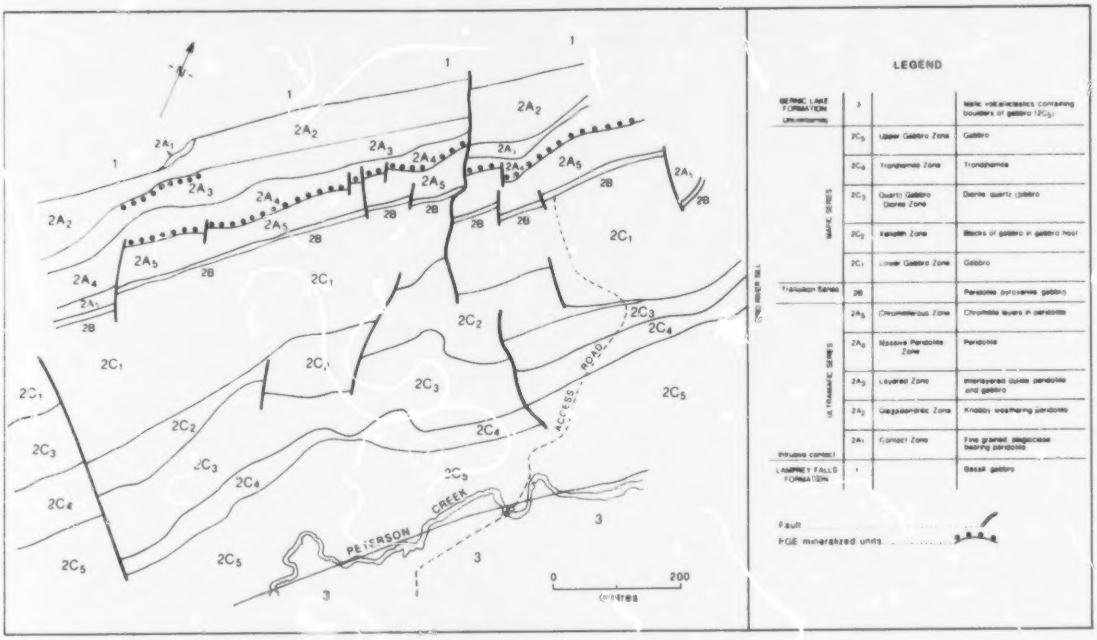
N
1
$2A_1$
$2A_2$
$2A_3$
$2A_4$
$2A_5$
2B
$2C_1$
$2C_2$
$2C_3$
$2C_4$
$2C_5$
3
ACCESS ROAD
PETERSON CREEK
0
200
metres
LEGEND
BERNIC LAKE FORMATION
Unconformity
3
Mafic volcaniclastics containing boulders of gabbro ($2C_5$)
BIRD RIVER SILL
MAFIC SERIES
$2C_5$ Upper Gabbro Zone
Gabbro
$2C_4$ Trondhjemite Zone
Trondhjemite
$2C_3$ Quartz Gabbro Diorite Zone
Diorite quartz gabbro
$2C_2$ Xenolith Zone
Blocks of gabbro in gabbro host
$2C_1$ Lower Gabbro Zone
Gabbro
Transition Series
2B
Peridotite pyroxenite gabbro
ULTRAMAFIC SERIES
$2A_5$ Chromitiferous Zone
Chromitite layers in peridotite
$2A_4$ Massive Peridotite Zone
Peridotite
$2A_3$ Layered Zone
Interlayered olivine peridotite and gabbro
$2A_2$ Megadendritic Zone
Knobby weathering peridotite
$2A_1$ Contact Zone
Fine grained plagioclase bearing peridotite
Intrusive contact
LAMPREY FALLS FORMATION
1
Basalt gabbro
Fault
PGE mineralized units

Figure 2. Geology of the Chrome Property.

BERNIC LAKE FORMATION			mafic volcaniclastics containing boulders of Upper Gabbro Zone; clastic sedimentary and volcanic rocks
unconformity (?)			
BIRD RIVER SILL	MAFIC SERIES	Upper Gabbro Zone (150 m)	gabbro; anorthositic gabbro
		Trondhjemite Zone (40-90 m)	trondhjemite; diorite; aplite dikes
		Quartz Gabbro - Diorite Zone (60-120 m)	massive and porphyritic diorite; quartz bearing and "chicken track" gabbro; aplite dikes
		Xenolith Zone (60-120 m)	blocks of medium to coarse grained gabbro in matrix of medium to coarse grained gabbro; glomeroporphyritc, pegmatitic and mela- gabbro
		Lower Gabbro Zone (90-220 m)	anorthosititc, pegmatitic, heterogeneous and mela- gabbro
	TRANSITION SERIES	Upper Peridotite Zone (6-12 m)	knobby peridotite; pyroxenite
		Gabbro Zone (8-9 m)	troctolite; gabbro
		Lower Peridotite Zone (3-7 m)	knobby peridotite
	ULTRAMAFIC SERIES	Chromitiferous Zone (40-60 m)	peridotite; chromitite (Lower, Disrupted, Lower Main, Banded & Diffuse, Upper Main and Upper Paired groups)
		Massive Peridotite Zone (40-50 m)	knobby and smooth weathering peridotite
		Layered Zone (40-60 m)	Gabbro subzone - troctolite: gabbro
			Layered subzone - knobby and smooth weathering peridotite; layered peridotite - chloritite
			Basal subzone - foliated and knobby peridotite: minor chromitite
		Megadendritic Zone (30-50 m)	megadendritic, knobby and smooth weathering peridotite
		Contact Zone (2 m)	fine grained plagioclase bearing peridotite
intrusive contact			
LAMPREY FALLS FORMATION			basalt; gabbro

Figure 3. Igneous stratigraphy of the Bird River Sill, Chrome Property.

The sill was intruded at 2754±5 Ma (zircon U-Pb age, Timmins et al., 1985) into metabasalts of the Lamprey Falls Formation, the second oldest of six formations that constitute the Bird River greenstone belt (Trueman, 1980). The upper contact is interpreted to be a fault which separates anorthositic gabbro of the sill from a series of debris flows that contain inclusions of anorthositic gabbro in addition to inclusions of metabasalt. The intrusion was apparently unroofed subsequent to its emplacement (Trueman, 1980).

The Sill is differentiated with a lower Ultramafic Series and an upper Mafic Series. Where the section has been measured, the Ultramafic Series is about 200 m thick and the Mafic Series is 400 m thick (Fig. 2 and 3). However, as the top of the sill has been eroded, the latter thickness is a minimum.

SUMMARY OF RESULTS

I.Stratigrpahy of the Bird River Sill and the contained chromitites and PGE-bearing units

Mapping during 1985 to 1988 resulted in the production of the following geological maps: 1) map of the property (1:2000 scale), an area of 0.9km x 1.2km; 2) detailed map of part of the Ultramafic Series (1:500 scale); and 3) four detailed maps (1:200 scale) showing 640m strike length of the Chromitiferous Zone. These maps are being prepared for GSC Open File publication. Some of the most important results of this mapping are summarized in the following account.

The stratigraphy of the Bird River Sill as proposed by Scoates (1983) was essentially confirmed, and is shown with the new modifications in figures 2 and 3. The previously defined Transition Zone (now Series) has been expanded into three zones because of the recognition of another peridotitic unit. In addition a new gabbroic subzone was discovered in the Layered Zone of the Ultramafic Series. Within the Mafic Series, mapping indicated that the Trondhjemite and Quartz Gabbro-Diorite Zones might represent a separate intrusion, and preliminary rare earth element analyses are consistent with this possibility.

Mapping of the Chromitiferous Zone demonstrated the remarkable stratigraphic consistency (Fig. 4) and original continuity of the chromitite layers, even to certain mm-scale details, along 600 m of strike length. A newly recognized feature was an additional, discontinuous chromitite layer below the base of the main Chromitiferous Zone.

Notwithstanding their large scale continuity, the chromitite layers display numerous local irregularities and discontinuities (Figure 5). These disruptions obviously postdate the formation of the layers, but appear to have occurred before complete crystallization of the crystal mush, and are therefore synmagmatic in origin.

Scalloped basal contacts of the chromitite layers (Figure 5b), and features simulating the load cast and "drop and sag" structures (Figure 5c, d) that are found in sedimentary rocks indicate that the originally planar chromitite layers experienced plastic deformation at the synmagmatic stage. These could be explained by the gravitational instability of denser chromitite overlying a partially crystallized cumulus olivine crystal mush. More brittle forms of disruption of individual chromitite layers (Figure 5e, f) are also observed, and must also represent synmagmatic deformation in a crystal mush medium.

Another form of deformation of chromitite layers occurs in the presence of "harrisitic" peridotite, an irregularly distributed variety in which the olivine is coarser and skeletal in habit. Where chromitite layers overlie "harrisitic" peridotite, they commonly form downward protrusions, or appear to be "intruded" by diapir-like masses of "harrisite" (Figure 6). Coarse-grained "pegmatoidal" masses, commonly mushroom-shaped and convex upward, which are in many instances associated with "harrisite" and disrupted chromitite layers, seem to indicate that volatile-enrichment of the magma may be involved in this process.

The distribution of anomalous concentrations of Platinum Group Elements has been shown by mapping and sampling to be roughly stratigraphically controlled. The best defined PGE zone is about one metre thick, along the base of the Chromitiferous Zone (Figure 2). It is associated with Lower Group chromitite and with a subjacent interval of peridotite containing sparse, irregularly disseminated sulphides. Occurrences of "harrisite", disruption of chromitite, and pegmatoids also are associated with the PGE zone. More detailed descriptions are given in a subsequent section. A second zone, discovered by Theyer (1985), is near the base of the Layered Zone in the Ultramafic Series (Fig. 2), and like the first is associated with sparsely disseminated sulphides and discontinuous, thin chromite layers and pods.

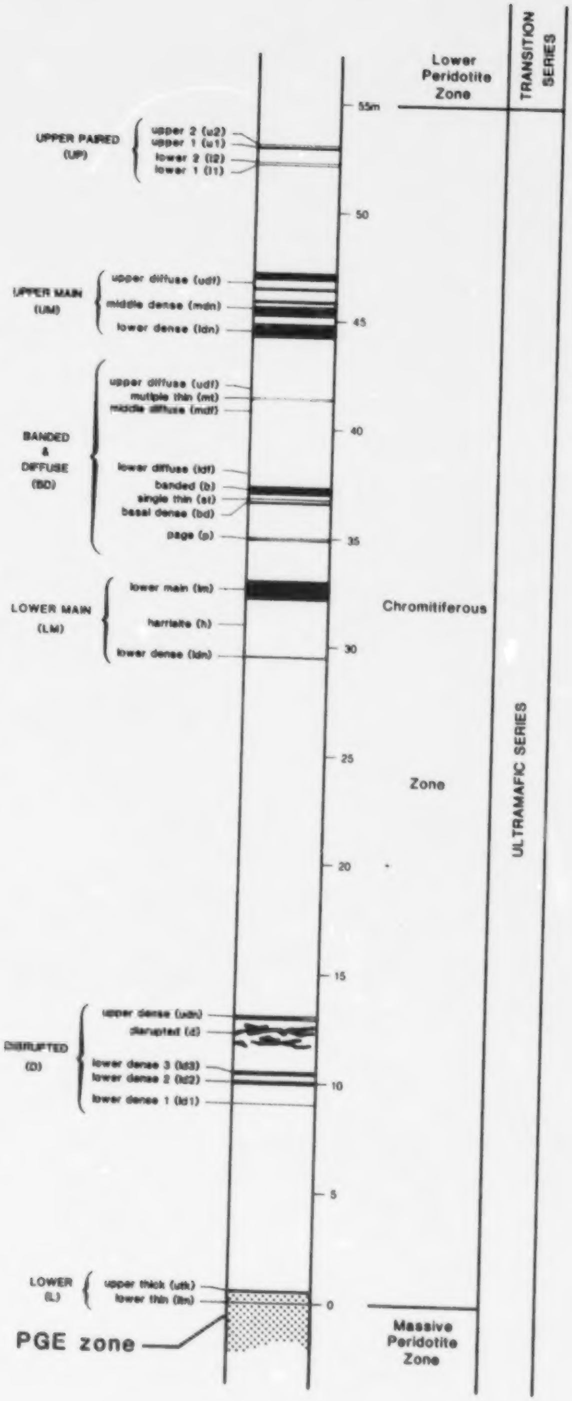
Lower Peridotite Zone
TRANSITION SERIES
55m
50
45
40
35
30
25
20
15
10
5
0
UPPER PAIRED (UP)
upper 2 (u2)
upper 1 (u1)
lower 2 (l2)
lower 1 (l1)
UPPER MAIN (UM)
upper diffuse (udf)
middle dense (mdn)
lower dense (ldn)
BANDED & DIFFUSE (BD)
upper diffuse (udf)
mutiple thin (mt)
middle diffuse (mdf)
lower diffuse (ldf)
banded (b)
single thin (st)
basal dense (bd)
page (p)
LOWER MAIN (LM)
lower main (lm)
harriaite (h)
lower dense (ldn)
Chromitiferous Zone
ULTRAMAFIC SERIES
DISRUPTED (D)
upper dense (udn)
disrupted (d)
lower dense 3 (ld3)
lower dense 2 (ld2)
lower dense 1 (ld1)
LOWER (L)
upper thick (utk)
lower thin (ltn)
PGE zone
Massive Peridotite Zone

Figure 4. Detailed stratigraphy of Chromitite Groups in the Chromitiferous zone of the Bird River Sill, Chrome Property.

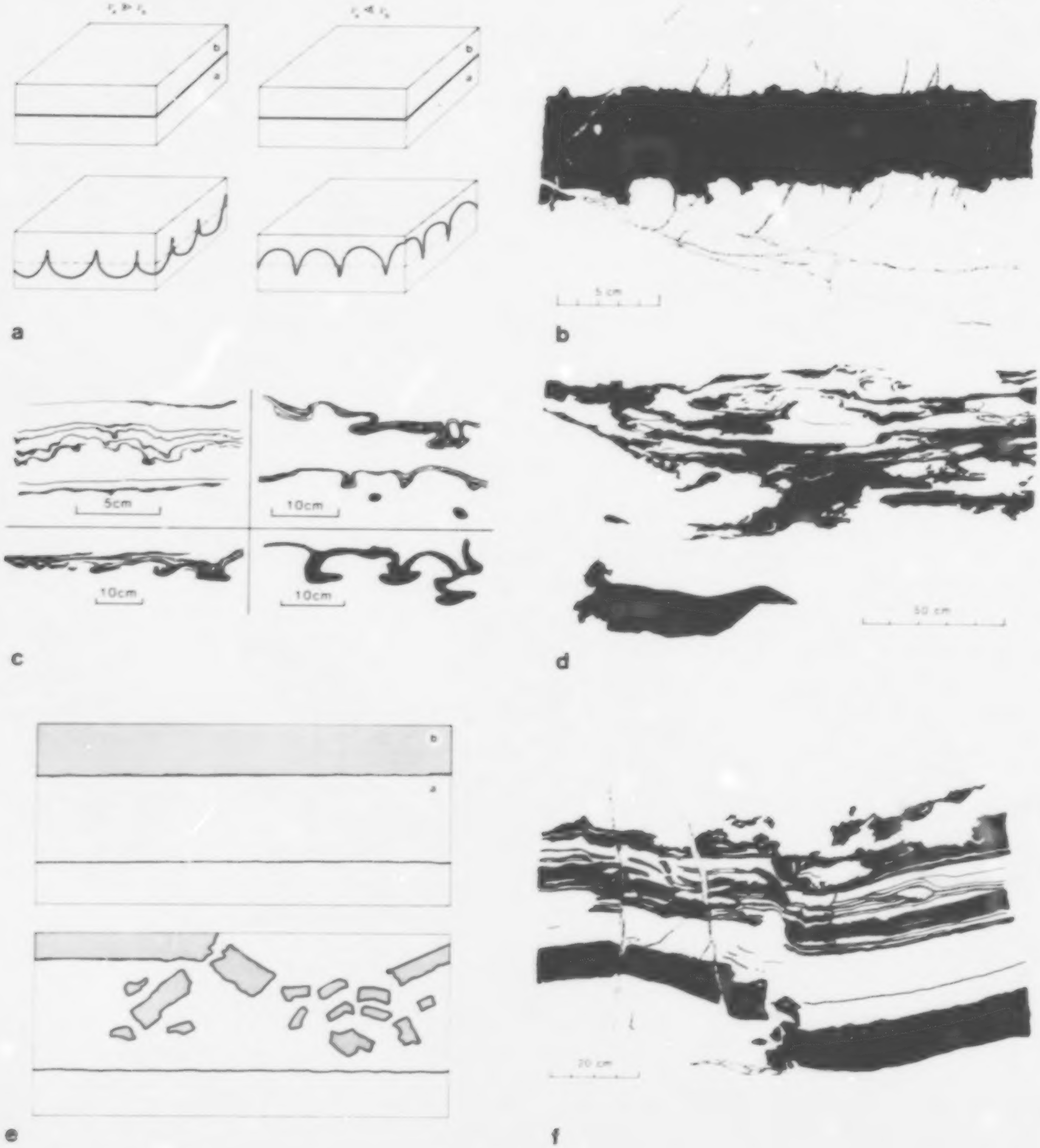

Figure 5. Soft sediment deformation structures. a) Experimentally developed load casts. Upper blocks show initial configuration and lower blocks final configuration of experimental system with layer "a" denser than layer "b". Layer "a" was more viscous than layer "b" in the experiment depicted on the left whereas the reverse was the case in the experiment depicted on the right. Adapted from Fig.1 in Anketell et al. (1970). b) Load casts developed in lower dense member of Lower Main Group. The lobate part of the casts protrude into the chromitite (black) indicating that it was more viscous than the peridotite layers on either side. Traced from a photograph. c) Drop and sag structures in heavy mineral layers in Torridonian sandstone. After Steward (1963 as reproduced in Allen, 1982). d) "Drop and sag" structure in disrupted member, Disrupted Group, Traced from a photograph. e) Brittle deformation in an experimental system where layer "b" is more viscous than layer "a", and layer "a" is prone to liquefaction. After Anketell et al. (1970, Fig. 16). f) "Liquid escape" or "flow through" structure in the Banded and Diffuse Group. The lower chromitite layer exhibits brittle behaviour whereas the uppermost layers show some ductile deformation. Traced from a photograph.

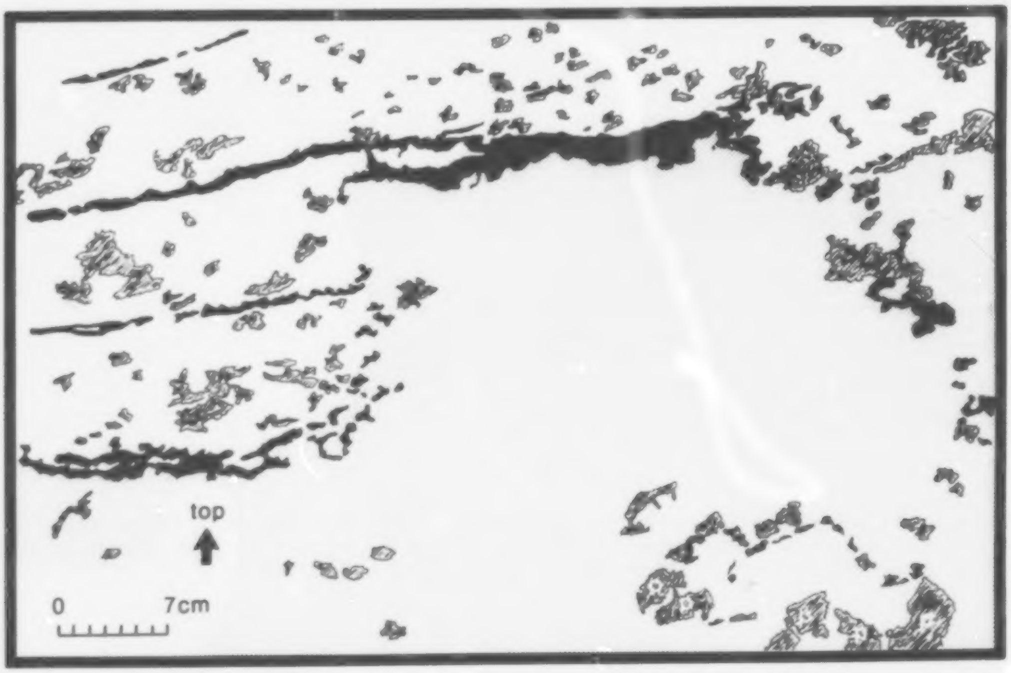

Figure 6. Relationships of chromitite (black), harrisite (shaded) and normal cumulate peridotite (white) at the base of the Lower Main Group, Chrome Property. The patterned areas are clinopyroxene oikocrysts and patches.

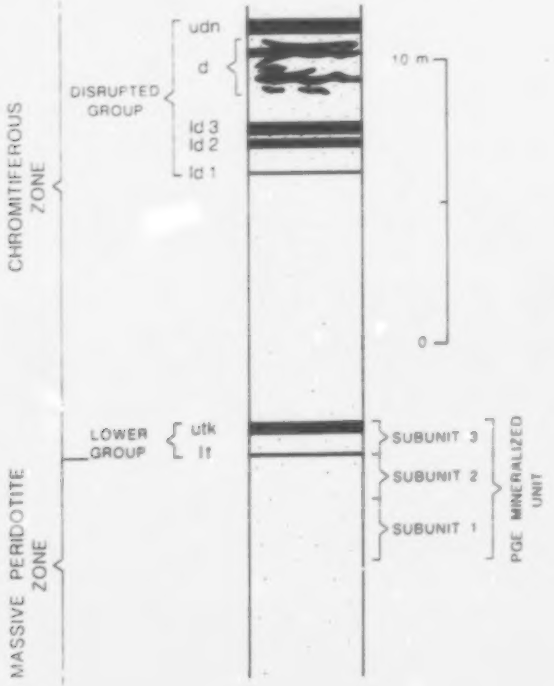
CHROMITIFEROUS ZONE
DISRUPTED GROUP
udn
d
ld 3
ld 2
ld 1
10 m
0
MASSIVE PERIDOTITE ZONE
LOWER GROUP
utk
lt
SUBUNIT 3
SUBUNIT 2
SUBUNIT 1
PGE MINERALIZED UNIT

Figure 7. Detailed stratigraphy of the contact between the Massive Peridotite Zone and the Chromitiferous Zone illustrating the subdivisions of the PGE mineralized unit. See Fig. 4 for abbreviations.

Subsequent to these primary magmatic processes, the sill has been subjected to greenschist facies metamorphism and tectonic deformation (Trueman, 1980). Consequently most primary minerals have been altered, although with surprisingly good preservation of original texture. Oblique block faulting with horizontal displacements ranging from centimetres to tens of metres has significantly disrupted stratigraphy, and would likely present problems for mine planning. It is not clear whether PGE have been mobilized significantly by these secondary processes.

II.GEOCHEMISTRY OF PGE MINERALIZATION

Anomalous PGE concentrations in Bird River Sill Ultramafic Series rocks are defined as those greater than 100 ppb combined Pt, Pd and Au. Four intervals containing anomalous PGE concentrations occur in the Ultramafic Series. Two have been reported from the western part of the Chrome Property in Ultramafic Series rocks stratigraphically below the Chromitiferous Zone (Theyer, 1985). A third occurs within and immediately below Lower Group chromitite (Lower Group platinum-bearing unit, Figure 4, 7). The fourth interval is the Disrupted Group (Fig. 4) where sporadically distributed anomalous PGE concentrations occur. Of the four intervals, the Lower Group platinum-bearing unit is the most continuous and the most consistently anomalous.

Lower Group Platinum-bearing Unit

This unit of anomalous PGE mineralization has been traced for 800 m along strike on the Chrome Property. The unit pinches and swells, ranging from several tens of centimetres up to three metres thick. The mineralized unit includes the Lower Group chromitites and extends downward below the base of the Lower Group into peridotite of the underlying Massive Peridotite Zone.

The mineralized unit has been divided provisionally into three subunits (Figure 7) on the basis of mineralogy and texture. Subunit 1, the stratigraphically lowest subunit, consists of disseminated-sulphide-bearing peridotite. The rocks are medium grained, original olivine crystals averaging 2 mm in size. Rounded to subangular chromitite inclusions are sporadically distributed throughout subunit 1, as are discontinuous, mm-scale chromitite layers. Coarser grained, harrisitic peridotite has been noted in places. Subunit 1 extends downward from 70 cm below to as much as 3 metres below the base of the Lower Group. Subunit 2 overlies subunit 1 and represents the 70 cm interval from the top of subunit 1 to the base of the Lower Group. Subunit 2 consists of disseminated-sulphide-bearing peridotite, much of which is characterized by coarse grained olivine crystals (up to 2 cm), many of which are harrisitic. The volume of original postcumulus material increases from 5 to 10 percent in subunit 1, to 20 percent in subunit 2. Chromite, as dense disseminations and disrupted fragments of dense chromitite is also more abundant than in subunit 1. Normal, fine grained peridotite is also present. Subunit 3 consists of the "lower thin" and "upper thick" chromitite members and the intervening olivine cumulate member of the Lower Group (see also Figure 4). The lower member is a 4 to 6 cm thick diffuse chromitite (chromite-olivine cumulate) layer that is disrupted in places and that locally bifurcates into two or more layers separated by peridotite. The chromitite is characterized by numerous peridotite inclusions up to 1 cm in size. The upper member ranges from diffuse to dense chromitite (10 to 25 cm thick) that commonly contains entrained peridotite inclusions. The chromitite locally bifurcates into two layers separated by up to 15 cm of peridotite. The olivine cumulate member that separates the lower and upper members ranges from fine grained peridotite (1 to 2 mm olivine) to coarse grained (1 to 2 cm olivine), harrisitic peridotite. The latter is commonly present where the lower member is disrupted. Disseminated sulphides are sporadically distributed throughout subunit 3.

The sulphides commonly occur as small clusters (a few millimeters in diameter) of tiny grains, clearly suggestive of intercumulus magmatic droplets. However recrystallization (under upper greenschist to lower amphibolite facies of metamorphism or during serpentinization) has produced fine grained sulphide-silicate intergrowth textures.

Platinum Group Minerals

All six platinum group elements are accounted for mineralogically by discrete platinum group minerals (PGM). These include in approximate order of abundance, sperrylite ($PtAs_2$), kotulskite ($PdTe$), merenskyite ($PdTe$), laurite (Ru_2S) hollingworthite ($RhAsS$), irarsite ($IrAsS$), keithconnite ($Pd_{3-x}Te$), and mertieite II (Pd_8Sb_3). The most common association of the PGMs is as tiny grains (usually <5μm) in silicate gangue (77% by volume, 91% by frequency) but some grains occur associated with sulphide (22% by volume, 3.6% by frequency) or included within chromite and magnetite (<1% by volume, 2.7% by frequency).

Platinum Group Element Geochemistry

Pt ranges up to 700 ppb and Pd up to 1800 ppb in assays of 66 samples from Ultramafic Series rocks (Table 1). Geometric means for subunits 1 through 3 (Table 2) show that the highest average concentration for total PGEs occurs in subunit 2, where Ni and Cu have the highest grades. Os, Ir and Ru have their highest concentrations in subunit 3 which contains the chromitite layers of the Lower Group.

Chondrite normalized profiles of PGEs are grouped according to their association (Fig. 8). Peridotite-hosted sulphidic PGE mineralization displays a steep positive slope, similar to that of other PGE-bearing magmatic sulphide deposits. PGE-poor chromitite has a negative slope, similar to the negative slopes shown by ophiolitic chromitites in general (Barnes et al., 1985). As in ophiolitic chromitites, this enrichment of Os, Ir and Ru in PGE-poor chromitites of the Bird River Sill expresses the tendency for laurite (Ru2S) and iridosmine (Os, Ir) to be the most common platinum group minerals (Talkington et al., 1983, Ohnenstetter et al., 1986). The third group in Figure 9, PGE-bearing chromitite has a shallow positive slope, intermediate between those of the other two groups. This profile appears to result from a combination of the high Os-Ir-Ru values of chromitite and the high Pt-Pd values of mineralized sulphidic peridotite.

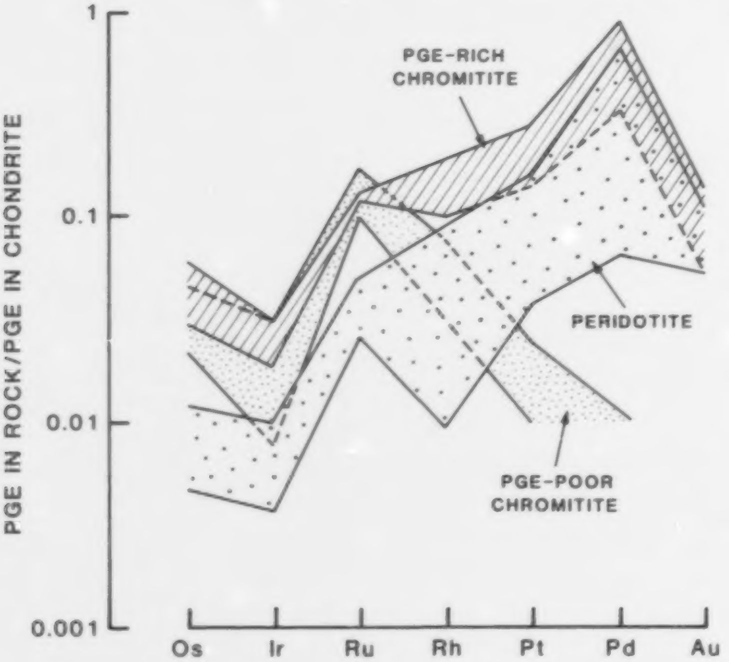

Figure 8. PGE profiles for rocks of the Bird River Sill. Data were normalized to the chondrite values used by Naldrett and Duke (1980). The range shown for peridotite is based mainly on subunits 1 and 2; the range for PGE-rich chromitite is based on the Lower Group (= subunit 3) and some values from the Disrupted Group; the PGE-poor chromitite range is based on other chromitites (Talkington et al., 1983) in the sill.

TABLE 1
Bird River Sill--PGE assays
(ppb, 66 samples)

Element	Minimum Value	Maximum Value
Os	1	100
Ir	1	53
Ru	3	510
Rh	1	160
Pt	17	720
Pd	2	1800
Au	4	520

TABLE 2.
Bird River Sill - Geometric Means of PGE in Mineralized Subunits

	Subunit 1	Subunit 2	Subunit 3
Os	4ppb	6ppb	15ppb
Ir	2	5	10
Ru	18	35	91
Rh	6	19	19
Pt	75	165	147
Pd	110	370	187
Au	15	17	8
Total PGE	230	617	477
Ni	2192 ppm	2936 ppm	1846 ppm
Cu	314	441	175
Cr	3511	5942	25811

The geometric mean (of Os, for example)=the antilog of the mean of the logarithms of all values of Os.

Through factor analysis, Scoates et al. (1988) revealed a clear association of PGE and chromite. The association of Os, Ir and Ru with chromite is to be expected because of the common occurrence of laurite inclusions, but the fact that Rh, Pt and Pd are also associated with chromite is surprising. There is no suggestion in the factor analysis of any association of PGE with sulphide. This is despite the facts that the PGE-enriched samples were derived from the unmineralized unit, which is the only unit that characteristically contains sulphides, and that the original sulphide melt is generally considered to have been the most PGE-enriched phase in the magma.

Discussion and Conclusions

Disseminated sulphides and anomalous PGE values in the Bird River Sill are mostly concentrated in a stratigraphic interval that includes the Lower Group chromitites. This crudely layer-like distribution of PGE, together with the textures of the sulphides is consistent with a magmatic genesis for both PGE and sulphides.

The soft-sediment-like, synmagmatic deformation of chromitite layers and the presence of harrisite immediately beneath dense chromitite layers in the Bird River Sill have been attributed to the upward migration of volatile-rich intercumulus liquid (Scoates et al., 1986a). This liquid, derived through compaction of the underlying pile of cumulus crystals, ponded beneath dense chromitite layers which are interpreted to have acted as semi-permeable membranes. Subsequent liquefaction of the underlying olivine cumulate mush produced the variety of soft-sediment-like deformational features observed in some chromitite layers. Harrisites and related pegmatites are thought to represent in-situ crystallization of volatile-rich intercumulus liquid under conditions of supercooling. Local disruption of Lower Group chromitites and the sporadic occurrence of coarse grained, harrisitic peridotite immediately beneath Lower Group chromitites illustrates the association of synmagmatic disruption of chromitites and the presence of harrisite with anomalous PGE concentrations.

The PGEs can be separated into two groups which show distinct geochemical tendencies. The Os-Ir-Ru group (IPGEs, Barnes et al., 1985) are strongly linked with chromite. This linkage probably reflects an early high temperature co-crystallization of IPGE with chromite, as has been suggested previously by others (e.g. Talkington et al., 1983).

The Rh-Pt-Pd group (PPGEs, Barnes et al., 1985) displays conflicting associations. On the one hand, mean abundances and PGE profiles seem to indicate that PPGEs are associated with a stratigraphic zone of sulphide mineralization. However factor analysis based on hand sample chemistry shows no association of PPGE with sulphide but rather a strong linkage with chromite. This seeming inconsistency could be explained in two different ways. It could result if the PPGEs were originally contained in intercumulus droplets of immiscible sulphide liquid associated with the harrisites. The PPGEs could then have been mobilized out of the sulphides (during crystallization of the sulphides? late magma crystallization? regional metamorphism?) and crystallized with some kind of spatial affinity for chromite. Another possibility is that the chromite and immiscible sulphide droplets were originally accumulated together in the chromitite layers of the Lower Group. Then during the upward ponding of the harrisite-forming intercumulus melt, the dense sulphide droplets partially settled out of the chromitite and into the underlying peridotite, but PPGE maintained some kind of spatial affinity for chromite.

The PPGE-chromite affinity is not obvious at microscopic scale; the PPGE-PGMs are mostly enclosed in silicates. This distribution could result from a further, local scale late remobilization of PPGEs away from chromite during serpentinization.

Continuing investigations involve detailed studies of mineralogy, texture and rock composition in relation to igneous stratigraphy and distribution of PGE in the various lithologic units. The objectives of these studies is the genetic understanding of the controls on PGE concentration and in particular the PPGE-chromite affinity.

III.COMPOSITION OF CHROMITE

In order to document the composition of chromite in the Bird River Sill, a contract reconnaissance study by David H. Watkinson, Raymond W. Talkington and Peter C. Jones of Carleton University was commissioned under the terms of a Canada-Manitoba Interim Agreement. This was followed up with a contract study by Frank C. Hawthorne, University of Manitoba, to carry out more extensive electron microprobe analyses. The results reported in the following account (Scoates et al., 1986b) are based on approximately 900 individual analyses of chromite grains in 182 samples from all six of the chromitite groups (Figure 4).

The compositional variation of chromite in the six chromitite layer groups is summarized in Figure 9. The chromites are inhomogeneous and the compositional variation may be resolved into a primary magmatic trend and a secondary metamorphic trend. The primary trend is attributed to reaction of cumulus chromite either with intercumulus liquid or with silicate minerals during subsolidus cooling. The secondary trend reflects the development of ferritchromite during regional metamorphism, commonly as rims around cores of magmatic chromite.

The compositional range within any given sample generally spans the range defined by all the samples of the same type (i.e. chromite cumulate, chromite-olivine cumulate, or olivine-chromite cumulate) in the particular layer group. Moreover, there is little difference among the compositional trends defined by the six layer groups. The exception is the trend for the Upper Paired Group which does not extend to such magnesian compositions as the others.

It is the chromite of the chromite cumulate type that constitutes most of the magmatic trend seen in figure 10. The composition of this chromite was little affected by metamorphism because of the high ratio of chromite to silicate minerals (about 1:1). However, much of the chromite of the chromite-olivine and olivine-chromite cumulate types experienced significant Fe-enrichment because of their generally lower chromite-silicate ratios, and thus these two types make up much of the metamorphic trend (Figure 10). Consequently only the Upper Main and Lower Main Groups of chromitites (made up mainly of chromite cumulates) have the economically favourable magmatic chromite compositions. The other Groups (Upper Paired, Banded and Diffuse, Disrupted and Lower; Figure 4), mainly comprising chromite-olivine and olivine-chromite cumulates, contain chromite that is largely of less favourable metamorphic composition. This could affect decisions concerning bulk vs. selective mining in defining potential chrome ore.

The fact that there is virtually no change in the composition of cumulus chromite throughout most of the Chromitiferous zone may indicate that the chromite formed from repeated influxes of new magma or, alternatively, that the zone of crystallization was replenished with primitive magma through a process such as convective rollover.

ACKNOWLEDGEMENTS

Important contributions to detailed mapping of the Ultramafic Series were made by summer students Bill Donaldson, Karen Hudson, Wendy Lewis, James S. Scoates and Pamela L. Schwann; and to reconnaissance mapping of the Mafic Series by W. John Russell. David F. Garson and Kim Nguyen carried out outcrop sampling by rock saw. Laboratory and office work on chromite compositions and textures were performed by Sandra Thompson.

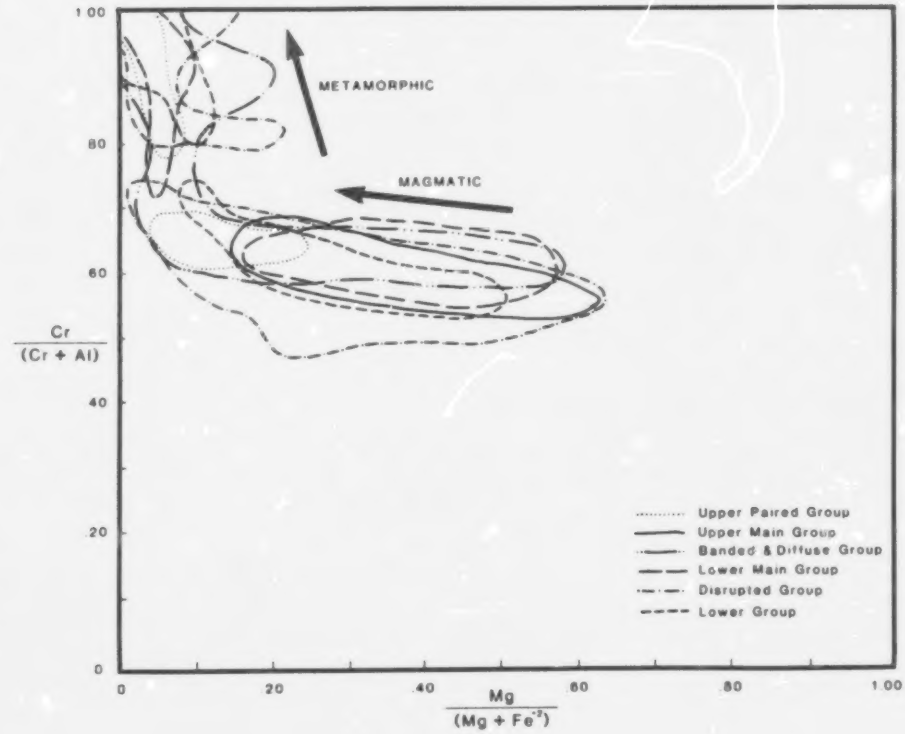

Fig. 9. Compositions of chromites from the six chromitite layer groups. The fields represent a total of about 900 microprobe analyses.

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THE FALCON LAKE INTRUSIVE COMPLEX

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INTRODUCTION

The Falcon Lake intrusive complex is located in southeastern Manitoba, near the Ontario border (Figure1). It is a composite intrusion approximately 5 km long and 2 km wide, with an elliptical- shaped core and tapered tabular extensions to the northeast and southwest (Figure 2). The complex is post-tectonic and retains its original intrusive orientation.

The body has always been of considerable interest, from both scientific and economic standpoints; scientifically, it has been recognised as a body that could provide new insights into the character and genesis of igneous layering, geochemical evolution of magmas, and chemical and physical intrusion processes. Economically, the body hosts, or has associated with its contacts, several small gold and sulphide deposits. These interests led to the implementation of the present study of the body, financed by the Geological Survey of Canada during the 1984-89 Canada-Manitoba Mineral Development Agreement.

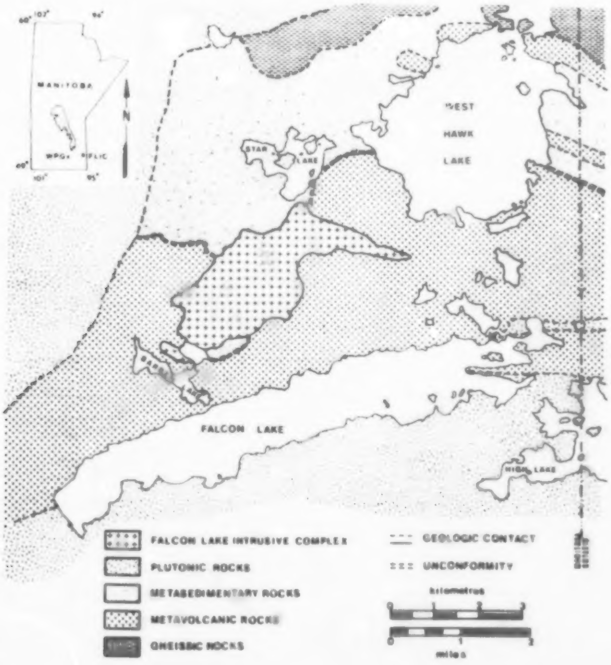
60° 102° 95°
MANITOBA
N
WPG
FLIC
49° 101° 95°
WEST HAWK LAKE
STAR LAKE
BARREN LAKE
FALCON LAKE
HIGH LAKE
FALCON LAKE INTRUSIVE COMPLEX
PLUTONIC ROCKS
METASEDIMENTARY ROCKS
METAVOLCANIC ROCKS
GNEISSIC ROCKS
GEOLOGIC CONTACT
UNCONFORMITY
kilometres
0 1 2 3
0 1 2
miles

Figure 1. Location and general geology around the Falcon Lake intrusive complex

The overall study consists of three parts: a field study of the intrusions and the primary structures (Mandziuk, 1988; Mandziuk et al., 1989), a geochemical study of the component intrusions and their magmatic evolution (Tirschmann and Halden, 1988), and a field based study of the mineral occurrences within and around the complex (Fingler, 1985, 1986, 1986a). The results of this work are presented in summary form in the following sections.

COMPONENT INTRUSIONS AND THEIR PRIMARY STRUCTURES

The Falcon Lake intrusive complex consists of a series of intrusions, ranging from four older gabbroic units (intrusions A,B,C,D) in the tabular extensions of the body, through younger diorite-granodiorite (intrusion E) in the outer part of the core, to youngest quartz monzonite (intrusion F) in the central part of the core (Figure 2). The rocks of the intrusion are characterized by either cumulate or porphyritic textures. The petrology, distribution and relative ages of the component intrusions as established in the field suggest that they were drawn sequentially from a differentiating magma chamber. Furthermore, the field relationships indicate that the complex was initially a tabular body, subsequently developed a larger, more cylindrical form, and in the waning stages became progressively more constricted towards the core (Figure 3).

The complex is typified by a variety of primary igneous structures which include planar laminations, mineral lineations, lineate laminations, layering, locallized discordant intrusive contacts (similar to angular unconformities), trough bands, mafic mineral clots, felsic mineral segregations, xenoliths , cognate inclusions, dykes and late-stage breccia pipes (Figures 4, 5, 6). The mineral orientation structures and layering are arranged concentrically within the complex and have steep dips (Figure 2).

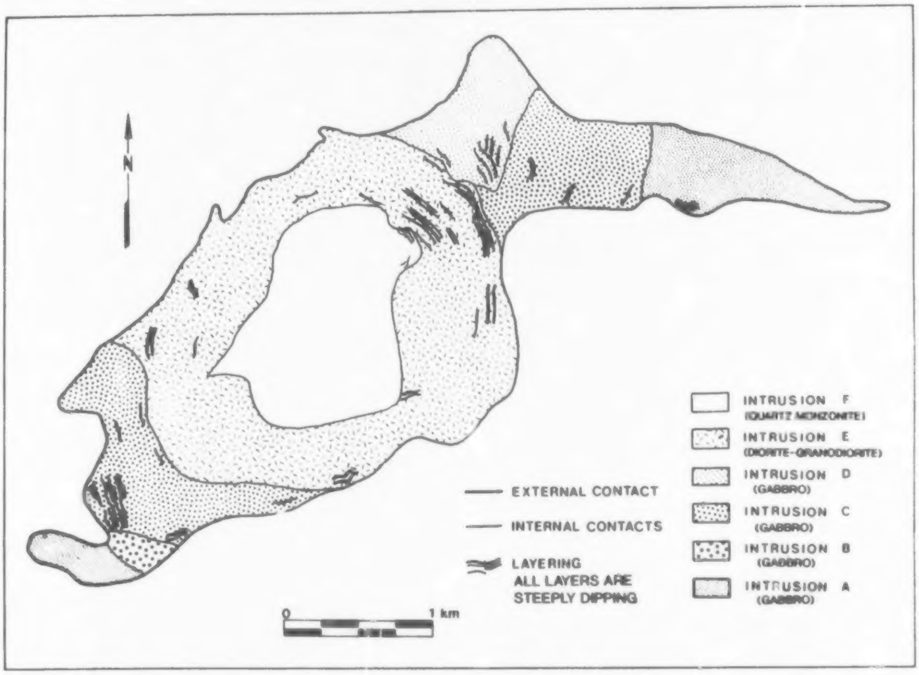

Figure 2. Geology of the Falcon Lake intrusive complex

The textures and primary structures indicate that each intrusion consisted of a crystal-liquid mixture and that magmatic flow was responsible for the discordant features, the mineral orientations and the layering. Periods of low velocity laminar flow, yielding sub-vertical concordant layering and mineral lineations, alternated with periods of high velocity turbulent flow which led to discordant structures. Possible origins of these fluctuations include intrusive surges, convection, or the periodic slumping of side walls and the development of density currents.

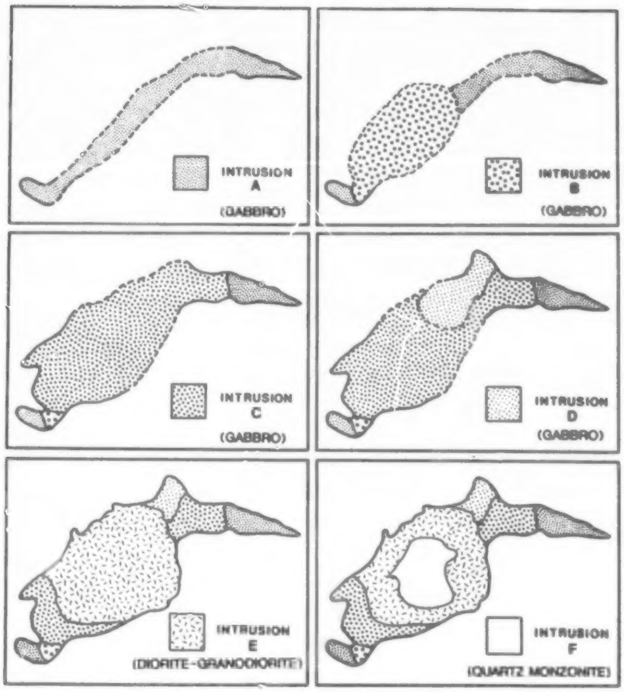
INTRUSION
A
(GABBRO)
INTRUSION
B
(GABBRO)
INTRUSION
C
(GABBRO)
INTRUSION
D
(GABBRO)
INTRUSION
E
(DIORITE-GRANODIORITE)
INTRUSION
F
(QUARTZ MONZONITE)

Fig. 3. Interpretation of the intrusive history of the complex (From Mandziuk, 1988).

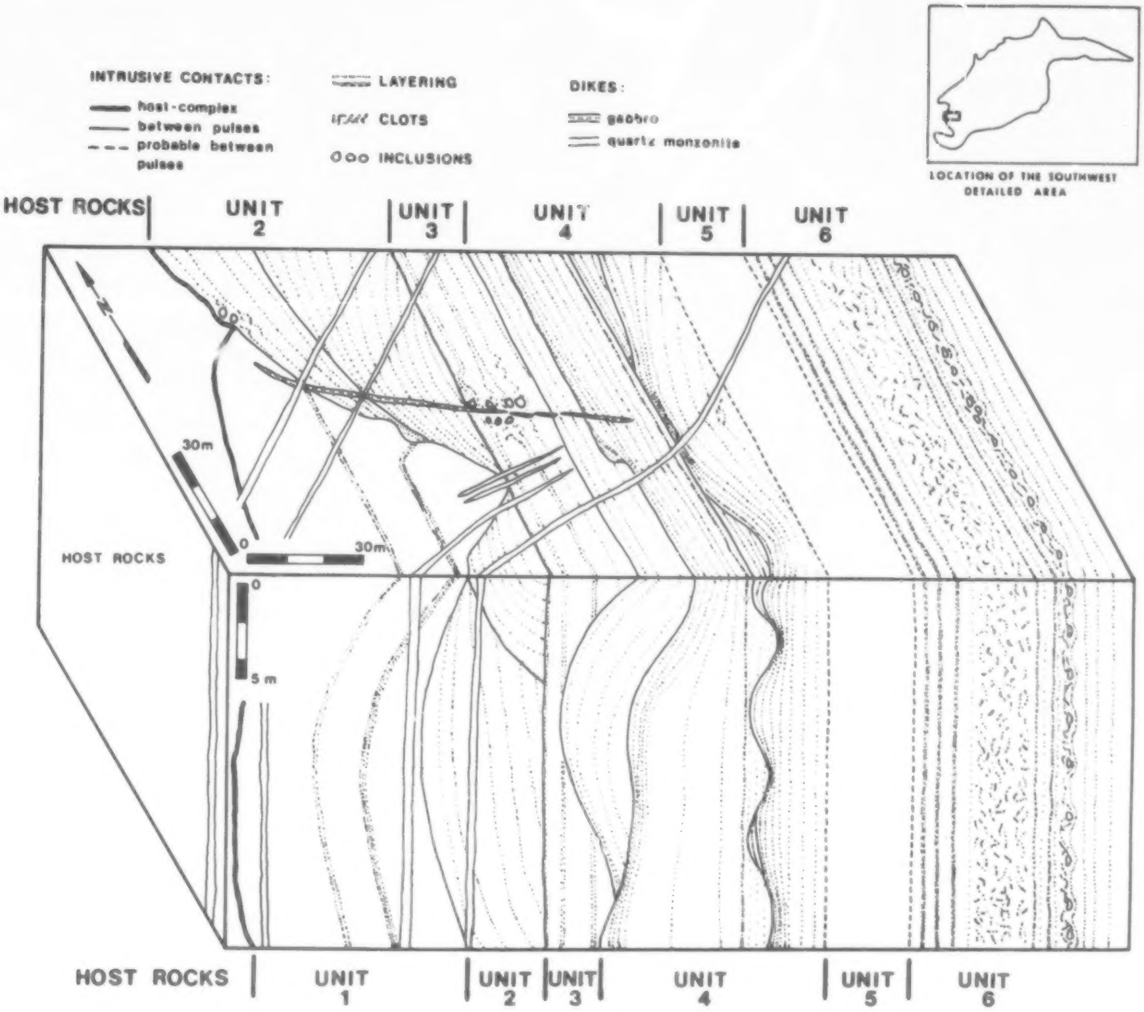
INTRUSIVE CONTACTS:
host-complex
between pulses
probable between pulses
LAYERING
CLOTS
INCLUSIONS
DIKES:
gabbro
quartz monzonite
LOCATION OF THE SOUTHWEST DETAILED AREA
HOST ROCKS
UNIT 2
UNIT 3
UNIT 4
UNIT 5
UNIT 6
N
30m
0
30m
HOST ROCKS
0
5 m
HOST ROCKS
UNIT 1
UNIT 2
UNIT 3
UNIT 4
UNIT 5
UNIT 6

Fig. 4. Igneous structures within intrusive units of intrusion D (gabbro) along the southwestern margin of the complex. Each unit has different layering characteristics. (From Mandziuk, 1988).

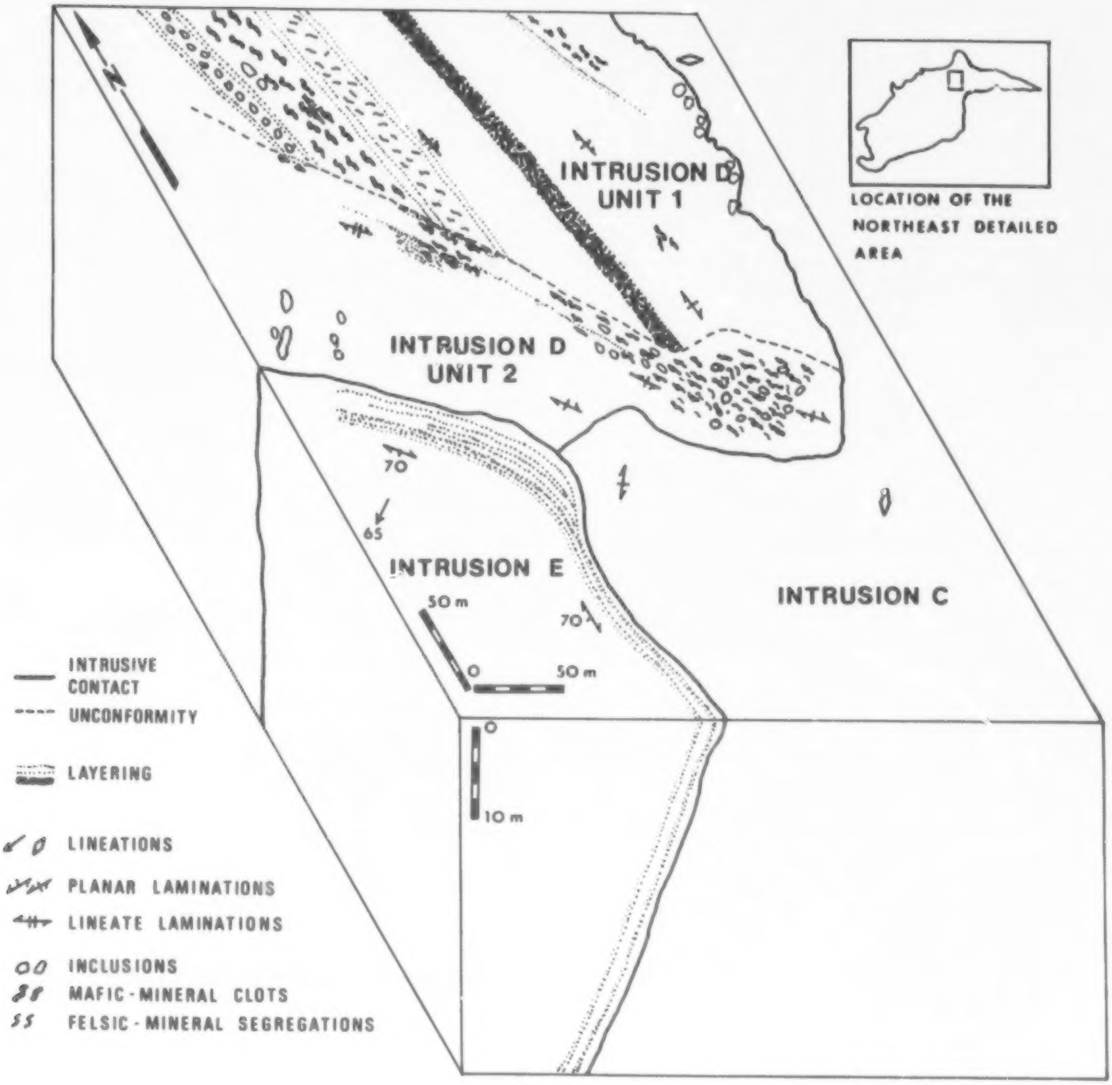
N
INTRUSION D
UNIT 1
INTRUSION D
UNIT 2
INTRUSION E
INTRUSION C
70
65
70
50 m
0
50 m
0
10 m
LOCATION OF THE
NORTHEAST DETAILED
AREA
INTRUSIVE CONTACT
UNCONFORMITY
LAYERING
LINEATIONS
PLANAR LAMINATIONS
LINEATE LAMINATIONS
INCLUSIONS
MAFIC-MINERAL CLOTS
FELSIC-MINERAL SEGREGATIONS

Fig. 5. Igneous relationships amongst intrusions C and D (gabbros) and intrusion E (diorite) in the northeastern part of the complex. Also shown are igneous structures in the different intrusions. (From Mandziuk, 1988).

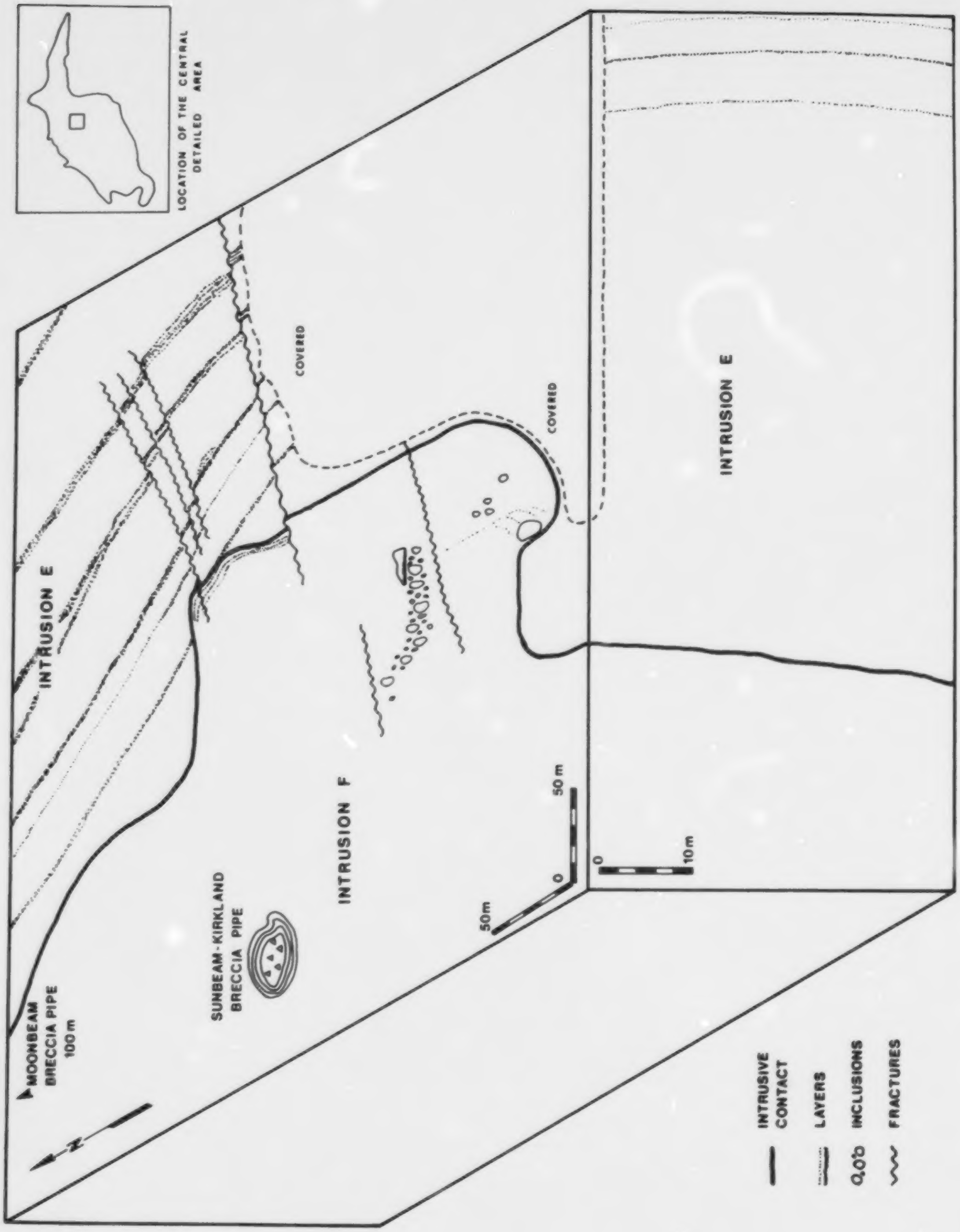
LOCATION OF THE CENTRAL DETAILED AREA
INTRUSION E
COVERED
COVERED
INTRUSION E
INTRUSION F
MOONBEAM BRECCIA PIPE 100 m
SUNBEAM-KIRKLAND BRECCIA PIPE
N
50m
0
50 m
0
10m
INTRUSIVE CONTACT
LAYERS
INCLUSIONS
FRACTURES

Fig. 6. Igneous relationships between, and structures within intrusions E (granodiorite) and F (quartz monzonite) along the northeastern margin of the complex core. (From Mandziuk, 1988).

GEOCHEMISTRY AND MAGMA EVOLUTION

The major element variations in the complex (Figures 7, 8) indicate that the geochemical evolution, from older gabbroic compositions to younger quartz monzonite, is consistent with that of a continuous differentiation series. However, there is significant compositional overlap between the intrusive units, indicating a series of discrete magmatic pulses each with its own liquid line of descent. These observations are consistent with a deep fractionating source from which the intrusive units were drawn, followed by further fractionation of each phase at the intrusive site.

The trace element variations (Figure 9) all suggest trends which reflect the operation of crystal-liquid fractionation processes. The variation of Sr with increasing SiO2 is of particular interest. In the early gabbro stages there is a trend of increasing Sr suggesting crystallization of olivine or pyroxene (in which Sr is incompatible) in the source mass, yeilding an increasing amount of Sr in successively evolved magmas.

Perhaps the most distinctive geochemical characteristic of the rocks of the complex is their light rare earth element enrichment (LREE). The La\Lu ratios are comparable to those of mafic to felsic alkaline rocks, lamprophyres and rocks of the K-rich basalt group. The consistency of the LREE enrichment pattern suggests that the component magmas of the complex were derived from the same source (Figure 10). The absence of any significant Eu anomalies (Figure 10) might be considered unusual, given the amount of plagioclase in the rocks of the complex; however this condition may point to high oxygen fugacity conditions in the source magma chamber. Accessory mineral phases in the complex, e.g. allanite, probably host the majority of the rare earth elements.

LREE enrichment seems to be a feature of other post-tectonic magmatism in the area as well. The Caddy Lake granite (Duncan, 1989), located five km north of the complex is also allanite-bearing and LREE-enriched. A speculative interpretation is that post-tectonic magmatism of this type could be indicative of a rifting environment.

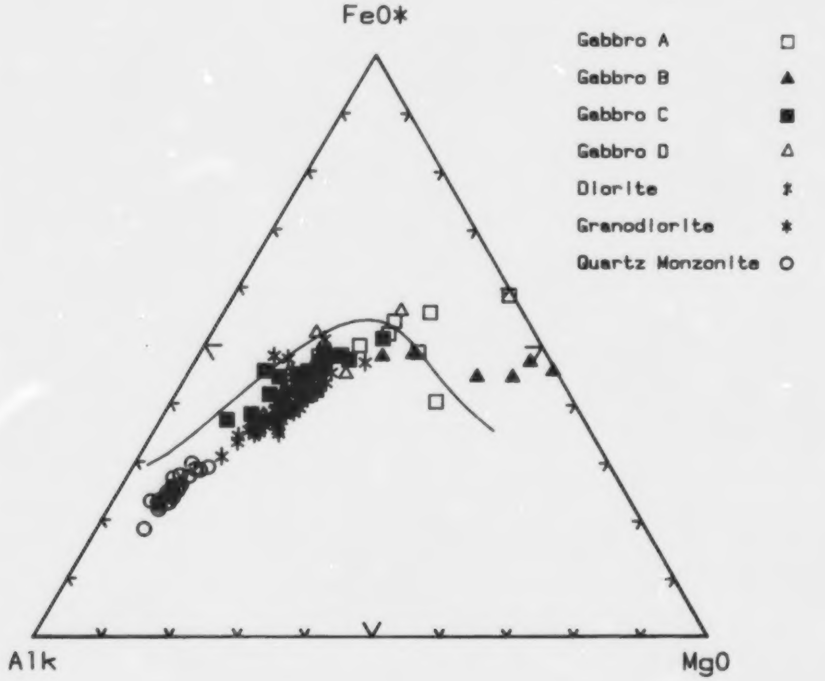

Fig. 7. AFM diagram for intrusions of the Falcon Lake intrusive complex. Diorite and granodiorite are grouped together as intrusion E.

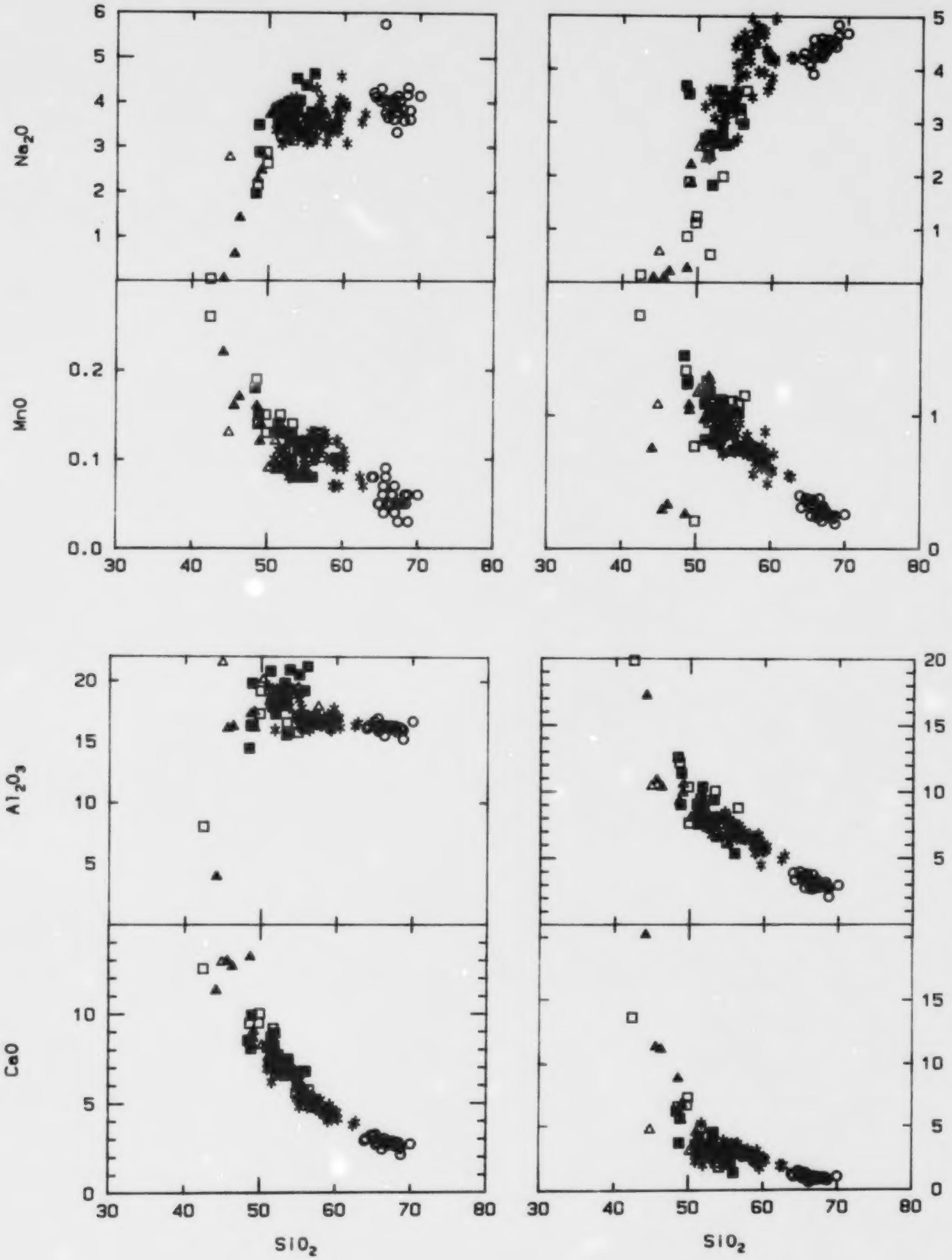

Fig. 8. Harker variation diagrams for rocks of the Falcon Lake intrusive complex. All elements expressed in weight % oxide. Symbols as in Fig. 7.

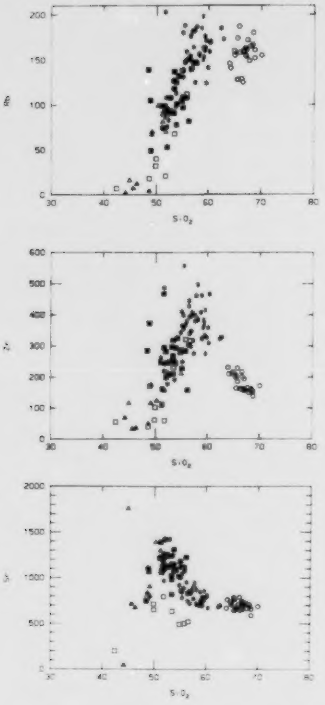

Fig. 9. Trace elements Zr, Sr, and Rb plotted against SiO2 for intrusions of the complex. Symbols as in Fig. 7.

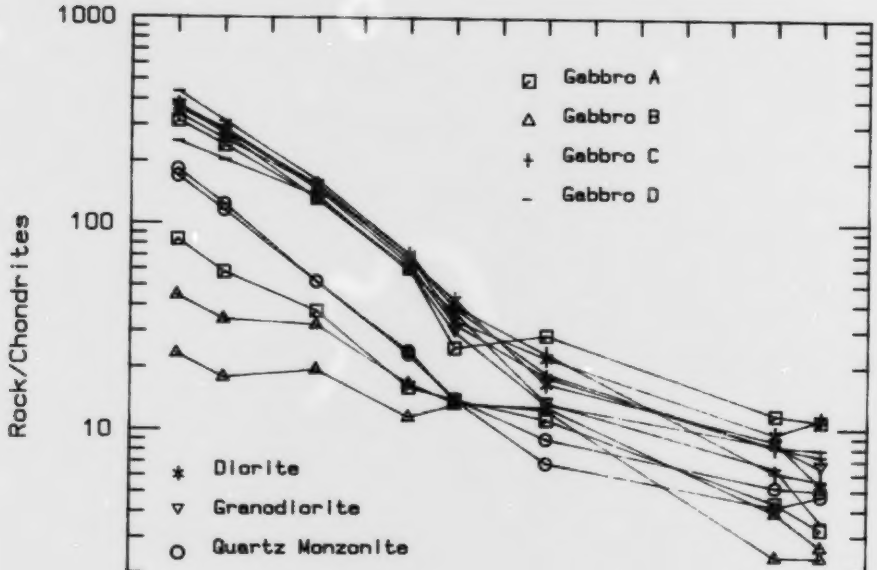

Fig.10. Chondrite-normalized REE plots of selected gabbroic and quartz monzonitic rocks from the Falcon Lake intrusive complex. Normalizing values from Thompson (1982).

MINERAL OCCURRENCES

The occurrences fall into three categories based on their spatial realationship to the complex: occurrences within, at the contact of, and marginal to the complex (Figure 11). Table I presents a summary of the geology of each of the occurrences.

The mineral occurrences contained within the complex all show evidence of a genesis related to fracturing and breccia pipe generation produced by hydrofracturing in the late stages of consolidation of the body. In some of these occurrences the shearing and veining are relatively simple, e.g. Sundog, Waverly. In other occurrences the deformation, mineralization and alteration show a more complicated history. The Sunbeam breccia pipe, as the best known of the mineral occurrences related to the complex, is a good case in point (Figure 12). In all cases the brittle deformation, mineralization and alteration appear to be broadly coeval and suggest late-stage, high pressure hydrothermal fluids as the major agent.

In contrast, the mineral occurrences at the contacts and in the marginal country rocks appear to be older, related more to processes of intrusion rather than to consolidation,and controlled in part by country rock stratigraphy. They are spatially related to a pre-intrusive unconformity between an older volcanic sequence and a younger clastic sequence, and in some cases to an iron formation at the unconformity, or to other iron formations in the volcanic pile just below the unconformity (Figure 13). In addition these occurrences are spatially related to the intrusive contact. This is a direct relationship for the Highway #1 and Denmark occurrences; apophyses of diorite or gabbro are part of the geology at the Moore, Narwark, Sheba and Gem occurrences; at the Rad and Thos. Boyes occurrences no intrusive rocks are known, however they are close by. The mineralization in each of these occurrences is complicated and different, reflecting a complex interplay amongst several factors such as permeability of the clastic sequence, fracturing of the volcanic units, and geochemical effects of iron formations associated with the unconformity. As well, there is the possibility that some of the mineralization in this group of occurrences may be genetically related to the host rocks rather than to the complex.

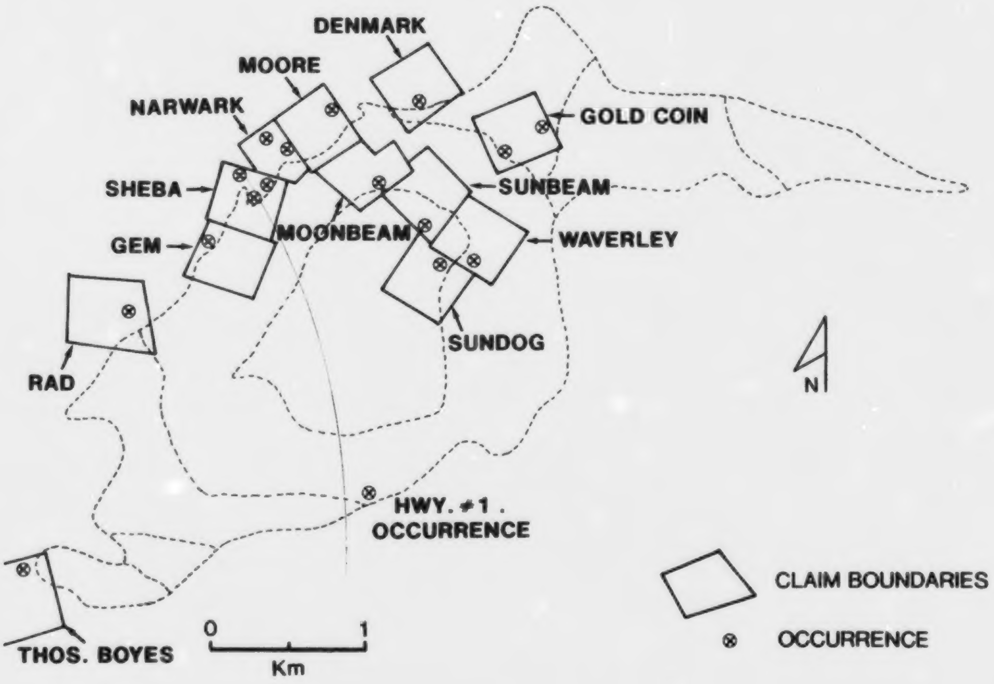

Fig.11. Locations of mineral occurrences related to the Falcon Lake intrusive complex. (From Fingler, 1985)

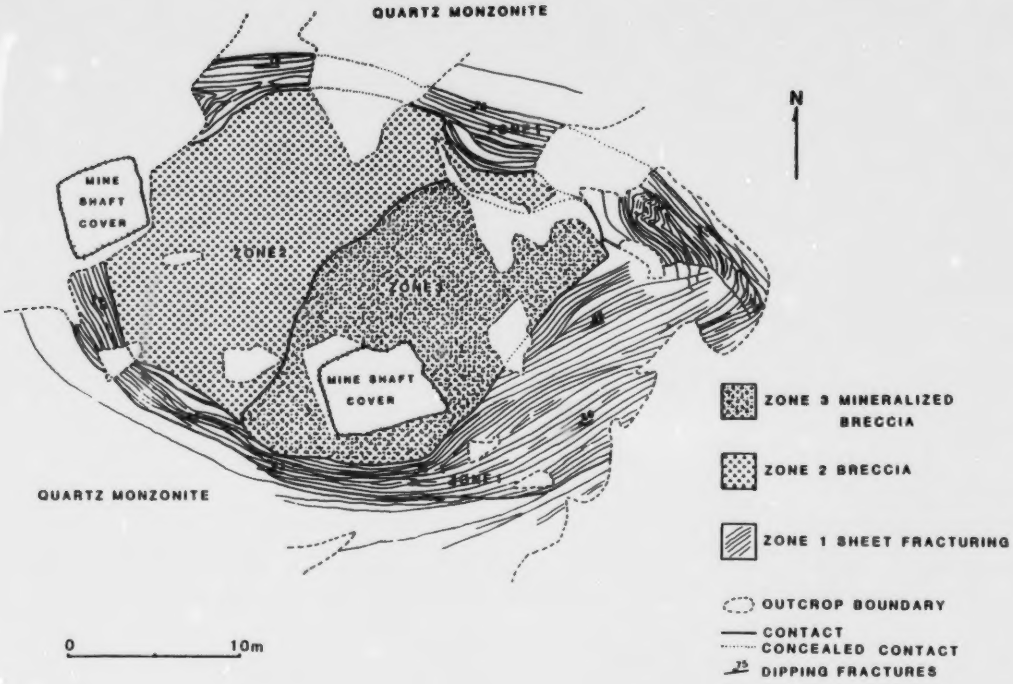
QUARTZ MONZONITE
N
MINE SHAFT COVER
ZONE 1
ZONE 2
ZONE 3
MINE SHAFT COVER
ZONE 1
QUARTZ MONZONITE
ZONE 3 MINERALIZED BRECCIA
ZONE 2 BRECCIA
ZONE 1 SHEET FRACTURING
OUTCROP BOUNDARY
CONTACT
CONCEALED CONTACT
DIPPING FRACTURES
0
10m

Fig.12. Detailed geology of the Sunbeam breccia pipe. (From Halwas, 1984).

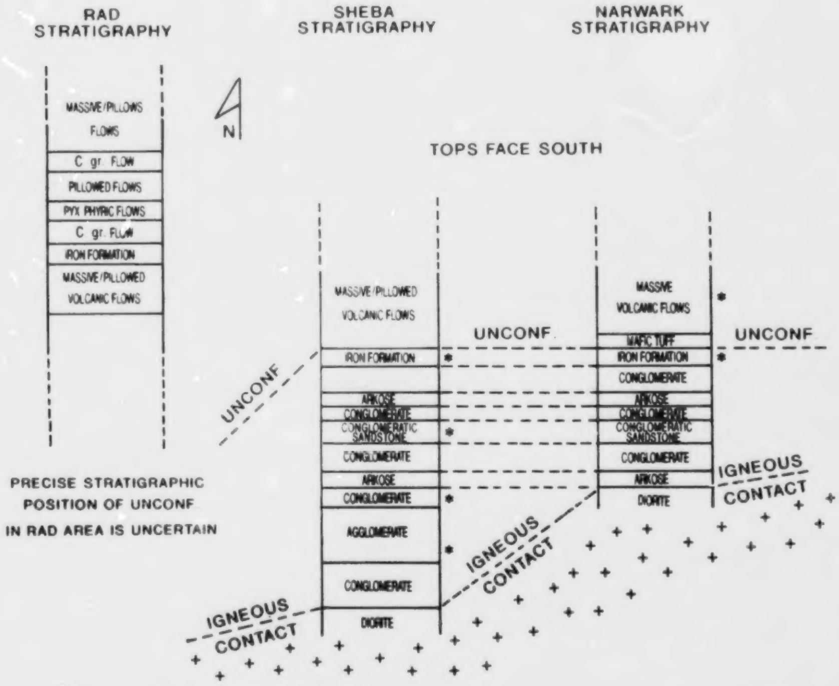
RAD STRATIGRAPHY
SHEBA STRATIGRAPHY
NARWARK STRATIGRAPHY
MASSIVE/PILLOWS FLOWS
C gr. FLOW
PILLOWED FLOWS
PYX PHYRIC FLOWS
C gr. FLOW
IRON FORMATION
MASSIVE/PILLOWED VOLCANIC FLOWS
N
TOPS FACE SOUTH
MASSIVE/PILLOWED VOLCANIC FLOWS
IRON FORMATION
ARKOSE
CONGLOMERATE
CONGLOMERATIC SANDSTONE
CONGLOMERATE
ARKOSE
CONGLOMERATE
AGGLOMERATE
CONGLOMERATE
DIORITE
UNCONF.
MASSIVE VOLCANIC FLOWS
MAFIC TUFF
IRON FORMATION
CONGLOMERATE
ARKOSE
CONGLOMERATE
CONGLOMERATIC SANDSTONE
CONGLOMERATE
ARKOSE
DIORITE
UNCONF
UNCONF
IGNEOUS CONTACT
IGNEOUS CONTACT
IGNEOUS CONTACT
PRECISE STRATIGRAPHIC POSITION OF UNCONF IN RAD AREA IS UNCERTAIN

Fig.13 Stratigraphy, igneous contacts and mineral occurrences, northern contact zone , Falcon Lake intrusive complex (from Fingler, 1985.)

CONCLUSION

The Falcon Lake intrusive complex is a post-tectonic, composite body consisting of component intrusions which were drawn from a differentiating chamber; each intrusion was subject also to some differentiation in situ. The intrusive processes were alternately dynamic and passive, and led to the development of subvertical concentric layering and mineral oriention fabrics, and produced a variety of other primary structures. The complex began as a dike and evolved into a cylindrical form which progressively constricted towards its center. Mineralization developed in the surrounding host rocks at various times during the intrusive history, particularly near an unconformity between older volcanic rocks and younger clastic sedimentary rocks. Late hydrothermal fracturing postdated all intrusions and produced mineralized shears and mineralized breccia pipes within the complex during its consolidation and cooling.

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THE FOX RIVER SILL: SOME ASPECTS OF ITS PETROGRAPHY, GEOCHEMISTRY AND PLATINUM-GROUP ELEMENT DISTRIBUTION IN PART OF THE MAIN LAYERED SERIES

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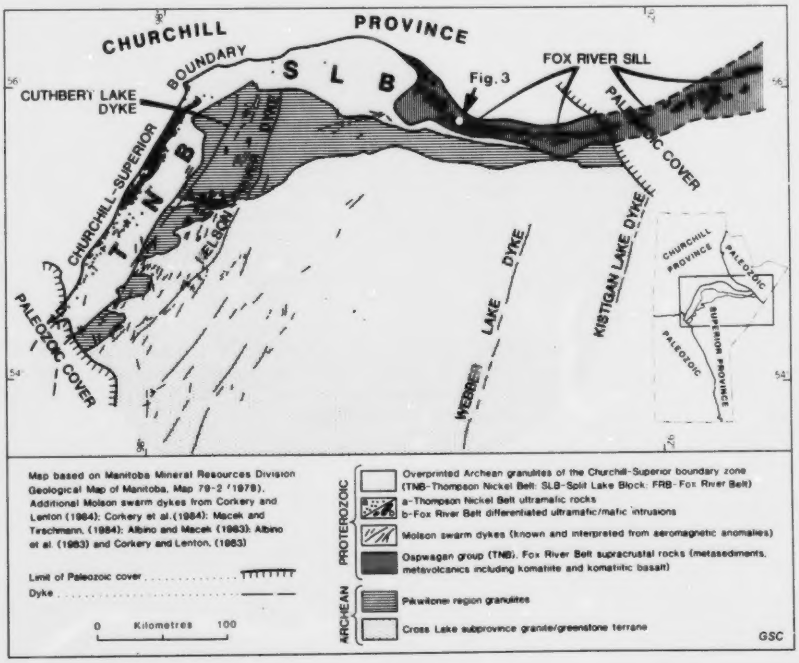
INTRODUCTION

Regional Geology

The Fox River Sill is a major layered, predominantly ultramafic intrusion located within the Fox River Belt of the Churchill Superior Boundary Zone in northeastern Manitoba (Figure 1). The Fox River Belt is a 15-20 km wide, steeply dipping, north-facing homoclinal sequence composed of sedimentary, ultramafic to mafic differentiated sills and volcanic rocks. Metamorphism is low grade, ranging from sub-greenschist facies at the stratigraphically highest levels increasing to lowermost greenschist facies at the stratigraphically lowest levels (Scoates, 1981).

Local Geology

The Fox River Sill, which at present erosional levels is 2 km thick, extends E-W along strike for 250 km, and dips steeply to the north. It is separated into an east and west lobe. The Fox River Sill has been subdivided into the Marginal Series, Main Layered Series, and Hybrid Roof Series, each characterized by distinctive rock type associations. The Marginal Series and Main Layered Series are


CHURCHILL
PROVINCE
BOUNDARY
CUTHBERT LAKE DYKE
S L B
Fig. 3
FOX RIVER SILL
PALEOZOIC COVER
CHURCHILL-SUPERIOR
T N B
NELSON
WEBBER LAKE DYKE
KISTIGAN LAKE DYKE
PALEOZOIC COVER
CHURCHILL PROVINCE
PALEOZOIC
SUPERIOR PROVINCE
PALEOZOIC
56°
54°
Limit of Paleozoic cover
Dyke
0 Kilometres 100
PROTEROZOIC
Overprinted Archean granulites of the Churchill-Superior boundary zone (TNB-Thompson Nickel Belt; SLB-Split Lake Block; FRB-Fox River Belt)
a-Thompson Nickel Belt ultramafic rocks
b-Fox River Belt differentiated ultramafic/mafic intrusions
Molson swarm dykes (known and interpreted from aeromagnetic anomalies)
Oapwagan group (TNB). Fox River Belt supracrustal rocks (metasediments, metavolcanics including komatiite and komatiitic basalt)
ARCHEAN
Pikwitonei region granulites
Cross Lake subprovince granite/greenstone terrane
GSC

Map based on Manitoba Mineral Resources Division Geological Map of Manitoba, Map 79-2 (1979). Additional Molson swarm dykes from Corkery and Lenton (1984); Corkery et al. (1984); Macek and Tirschmann, (1984); Albino and Macek (1983); Albino et al. (1983) and Corkery and Lenton, (1983)

Figure 1. Tectonic setting of the Fox River Sill

further distinguished by a regular cyclic arrangement of rock types, (Figure 2) (Scoates, 1981). A brief description of the three Series is summarized from Scoates, (1981) and Scoates and Eckstrand (1986). The Marginal Series is a repeated succession of layered peridotite, pyroxenite and gabbro which ranges up to 300 m thick. Peridotite and pyroxenite are plagioclase bearing, and gabbros contain minor amphibole. The Main Layered Series consists of a 2000 m succession of cumulate rocks. It has been subdivided into the Lower Central Layered Zone, a succession of predominantly ultramafic rocks composed of repeated cyclic units of thick dunite layers alternating with thinner peridotite and pyroxenite layers, and the Upper Central Layered Zone, an 1100 m succession of ultramafic and mafic rocks consisting of numerous repetative, small scale cyclic units composed of variations of dunite, peridotite, pyroxenite and gabbro. The Hybrid Roof Series is the thin (50 m) uppermost zone of the Fox River Sill. It is primarily composed of quartz granophyre-bearing gabbronorite, medium-grained to pegmatitic gabbro, and hosts inclusions of partially assimilated sedimentary rocks.

This contribution is based on material collected for an MSc. thesis which was completed in March, 1989 (Schwann, 1989) and supported in part by the Manitoba Mineral Development Agreement. A section from the westernmost part of the Fox River Sill which intersected part of the Main Layered Series (the upper 50 m of LCLZ, the LCLZ/UCLZ contact and the lower 600 m of UCLZ strata) was studied (Figure 3).

PETROGRAPHY AND STRATIGRAPHY OF THE ROCKS UNITS

The Fox River Sill is comprised of cumulus ol +/- chr (dunite); ol +/-cpx +/-chr (peridotite); cpx + ol +/- chr (olivine clinopryoxenite); and pl + cpx +/- ol (gabbro - olivine gabbro). The cumulates are interlayered in a systematic rhythmic succession and represent cyclic units. A complete cyclic unit is represented by dunite, peridotite, olivine clinopyroxenite and gabbro. Few of the cylcic units are fully developed, more commonly the rock sequence progresses through two or three rock types before being repeated. A minimum of thirty-two cyclic units were recognized from the LCLZ/UCLZ contact upward. Thick, homogeneous non-cumulus ilmenomagnetite-bearing gabbro and minor ilmenomagnetite-bearing gabbro apophyses intrude the cumulate succession.

The transition between LCLZ to UCLZ rocks is marked by a change in character of the rock from ultramafic in the LCLZ to a combination of ultramafic and mafic rocks in the UCLZ. Thick sequences of dunite and peridotite commonly capped by thin olivine clinoyproxenite layers in the LCLZ yield to thinner dunite and peridotite capped by thicker olivine clinopyroxenite and gabbro layers in the UCLZ. Plagioclase occurs as a common, cumulus mineral and sulphides, which are sparsely distributed in LCLZ rocks (Scoates and Eckstrand, 1981) are a ubiquitous, albeit minor component of UCLZ rocks. The contact between LCLZ and UCLZ rocks is also accompanied by a decrease in whole rock nickel content. In thick, sulphide-poor dunite - peridotite sequences in both the LCLZ and UCLZ, fluctuations in whole rock Ni content likely marks the sites of new magma influxes that are otherwise not evident (as suggested by Irvine and Smith, 1967).

SULPHIDE AND OXIDE DISTRIBUTION

Sulphide minerals within the Fox River Sill are minor but ubiquitous, seldom exceeding 3 volume percent. The overall sulphide mineralogy is relatively simple, principally consisitng of iron-nickel-copper-sulphur assemblages. Pyrrhotite (po), pentlandite (pn), chalcopyrite (ccp), cubanite (cbn), mackinawite (mkw) and pyrite (py) are the prevalent sulphide minerals. They commonly form polymineralic grains with po or pn cores bordered by ccp. Galena (gn), sphalerite (sph) and bornite (bn) are minor sulphide phases. The sulphide assemblages vary with rock type. Peridotite is Ni-sulphide rich, and contains po-pn assemblages which have been partially replaced by py and magnetite (mgn). Cu-bearing sulphide minerals are notably absent. Pyroxenite is Cu-sulphide rich, containing po-pn-ccp-cbn-mkw; gabbro is relatively sulphide deficient containing fine, disseminated ccp-gn-gn or in highly saussuritized samples, secondary veinlets of gn-bn. Grain size ranges between 0.01 and 0.5 mm and may reach 5 mm in peridotite with net-textured sulphides. Mgn is the predominant alteration product of sulphide minerals, although py and small amounts of marcasite, tochilinite and millerite have been noted.

The interstitial nature of the Cu-Fe-Ni sulphide assemblages as well as the internal textural relationships of the grains suggest that monosulphide solid solutions have precipitated from sulphide melts and upon further cooling have exsolved discrete sulphide minerals. Sulphides were subsequently remobilized and recrystallized with silicate minerals to give tne secondary mineralogical and textural sulphide assemblages.

PGE DISTRIBUTION

Anomalous concentrations of PGE (Pt + Pd > 100 ppb) occur at three stratigraphic intervals and are referred to as the Lower Mineralized Unit (LMU), Middle Mineralized Unit (MMU) and the Upper Mineralized Unit (UMU).

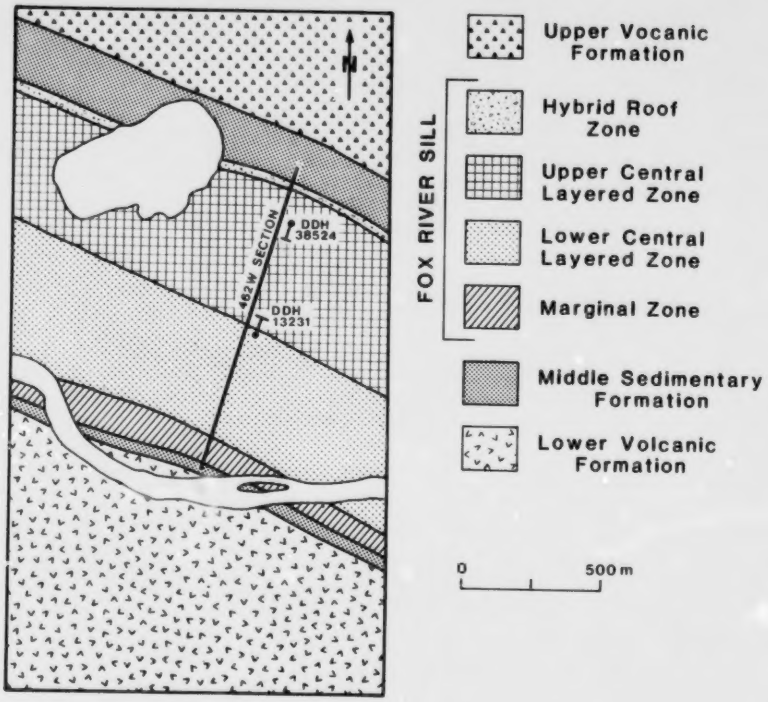

N
DDH 38524
DDH 13231
462 W SECTION
Upper Vocanic Formation
FOX RIVER SILL
Hybrid Roof Zone
Upper Central Layered Zone
Lower Central Layered Zone
Marginal Zone
Middle Sedimentary Formation
Lower Volcanic Formation
0
500 m

Figure 2. Geologic map illustrating the position of 462 W Section Line and drill holes, (after Scoates and Eckstrand, 1986)

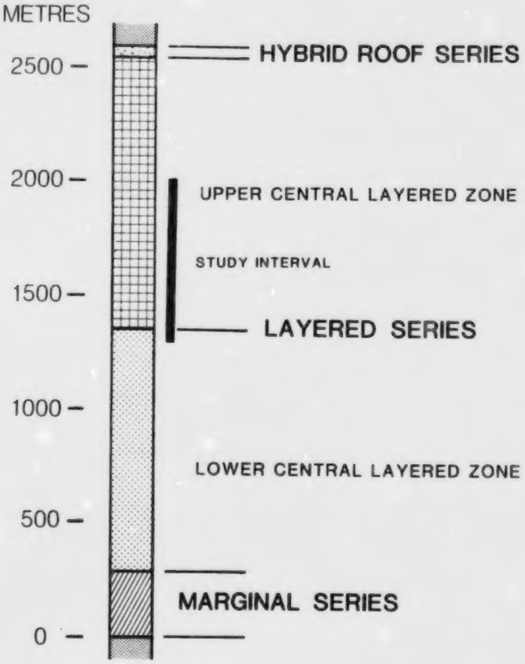

METRES
2500
2000
1500
1000
500
0
HYBRID ROOF SERIES
UPPER CENTRAL LAYERED ZONE
STUDY INTERVAL
LAYERED SERIES
LOWER CENTRAL LAYERED ZONE
MARGINAL SERIES

Figure 3. Composite stratigraphic section of the Fox River Sill (after Scoates, 1981)

1. Lower Mineralized Unit (Figure 4A)

PGE abundances (Pt + Pd) range from <25 to 800 ppb. The LMU is a succession of thinly interlayered rhythmic units of peridotite and pyroxenite which transgress the LCLZ/UCLZ contact. Olivine clinopyroxenite laminae and layers are predominant and tend to be thicker (5 cm - 5 m) than peridotite laminae and layers (10 cm - 2.5 m). Although the range of PGE abundances is greater in the peridotite, both the median and average PGE concentrations are higher in pyroxenite. Contacts between the peridotite and pyroxenite layers are generally sharp and do not show any sign of tectonic disruption. There is no gabbro in the LMU.

2. Middle Mineralized Unit (MMU) (Figure 4B)

PGE abundances (Pt + Pd) range from <100 ppb to 625 ppb. The MMU occurs over a 50 m stratigraphic succession of dominantly thick olivine clinopyroxenite layers interlaminated with thin peridotite and locally with olivine gabbro. Pyroxenite, the predominant mineralized rock type within this interval, exhibits the greatest range, and has the highest median and average of PGE abundances. Contacts are generally not faulted.

3. Upper Mineralized Unit (UMU) (Figure 4C)

Sporadic anomalous (Pt + Pd > 100 ppb) PGE concentrations range up to 980 ppb. The UMU contains the highest proportion of gabbroic rocks and represents products of the most fractionated magma in the study area. Peridotite, pyroxenite and gabbro in the UMU all contain PGE abundances, with pyroxenite being the preferential host of PGE mineralization. The highest PGE concentrations occur within a 5 m thick olivine clinopyroxenite layer. A thick peridotite containing fault breccia is overlain by a 5 m thick olivine clinopyroxenite which contains a thin (5 cm) peridotite lamina near its base. The olivine clinopyroxenite changes abruptly upsection to a coarse-grained to pegmatitic interval (1 m thick) which abruptly changes back to a homogenous medium-grained olivine clinopyroxenite for the upper 0.5 m. The olivine clinopyroxenite is capped by gabbro. Peak PGE abundances are concentrated in the sulphide-bearing, coarse-grained to pegmatitic interval of the olivine clinopyroxenite. In the UMU contacts between gabbroic rocks and overlying peridotite are often marked by fault breccia or gouge in the peridotite, and extensive recrystallizaon of the upper gabbro member. Fault breccias within individual rock types are also common.

Although pyroxenite is the dominant host rock for PGE, the proportions of rock types hosting PGE changes with increasing stratigraphic height (Figure 5). Peridotite is commonly host to PGE in the LMU, however, within the MMU and the UMU there is a progressive decrease in the proportion of PGE-bearing peridotite. Conversely, PGE mineralized gabbroic rocks which are absent in the LMU become successively more common within the MMU and UMU respectively. This trend suggest that with increasing stratigraphic height PGE abundances occur in more fractionated rock types.

Os, Ir and Ru abundances are consistently less than Pt and Pd. Peridotite contains higher levels of Os, Ir and Ru than pyroxenite or gabbro, and rocks from the LMU contain higher levels of Os + Ir + Ru than those of the MMU and UMU (Figure 6A). Pd levels are higher than Pt in peridotite; pyroxenite and gabbro range from Pd to extremely Pt enriched (Figure 6B). Pyroxenite and gabbro from the UMU contain higher proportions of Pt and Pd than similar rocks from the MMU and LMU. Advanced fractionation of new magma pulses accompanied by late sulphide saturation (as advocated by Scoates and Eckstrand 1986) would effectively partition these two groups and concentrate the more soluble Pt + Pd + Rh in more fractionated rocks.

GEOCHEMICAL ASSOCIATION OF THE PGE

As no PGM were identified, PGE, Cu, Ni, S, Se and Cr abundances were plotted against stratigraphic height to determine which elements displayed similar distribution patterns.

1. Lower Mineralized Unit (LMU - Figure 4A)

In the LMU, PGE, Cu, Se and S abundances exhibit similar profiles. Ni distribution roughly approximates that of the PGE. Cr distribution does not resemble PGE or base metal sulphide (BMS) abundances. Increases in Pt/(Pt + Pd) generally do not correspond to increases in Cu/(Cu + Ni). Se/S * 10^6 ratios are consistently low. Increases in PGE abundances seem to correspond to the presence of pyroxenite rather than peridotite, and the Cu/(Cu + Ni) profiles indicates that pyroxenite is more Cu-rich than peridotite which is Ni-rich.

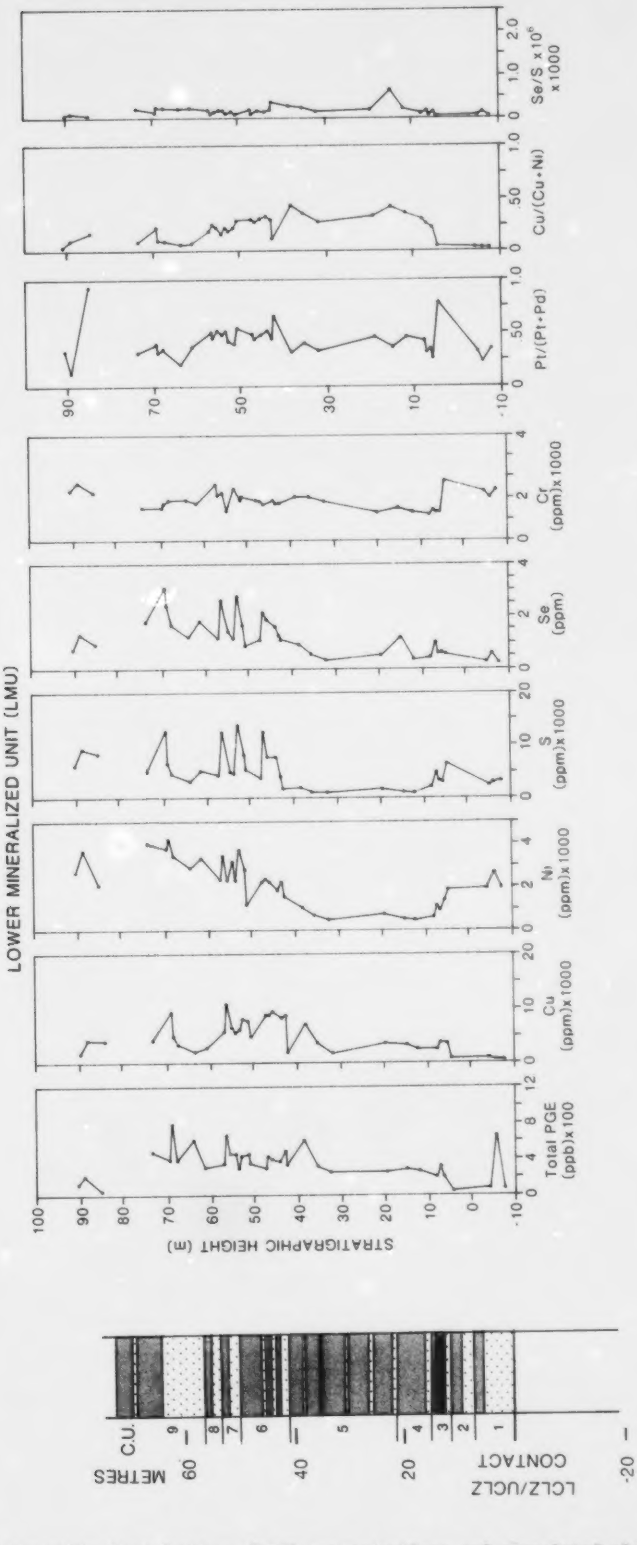


Figure 4A. Stratigraphic distribution of PGE concentrations and associated elements in the Lower Mineralized Unit

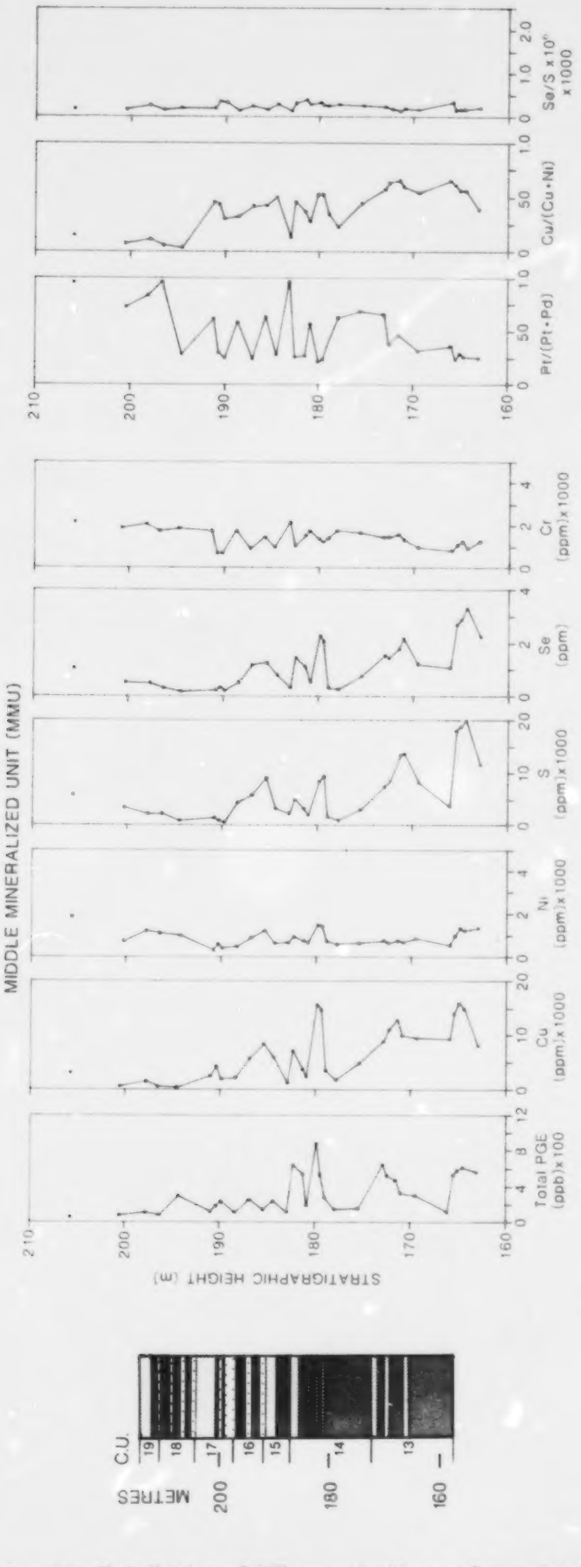


Figure 4B. Stratigraphic distribution of PGE concentrations and associated elements in the Middle Mineralized Unit.

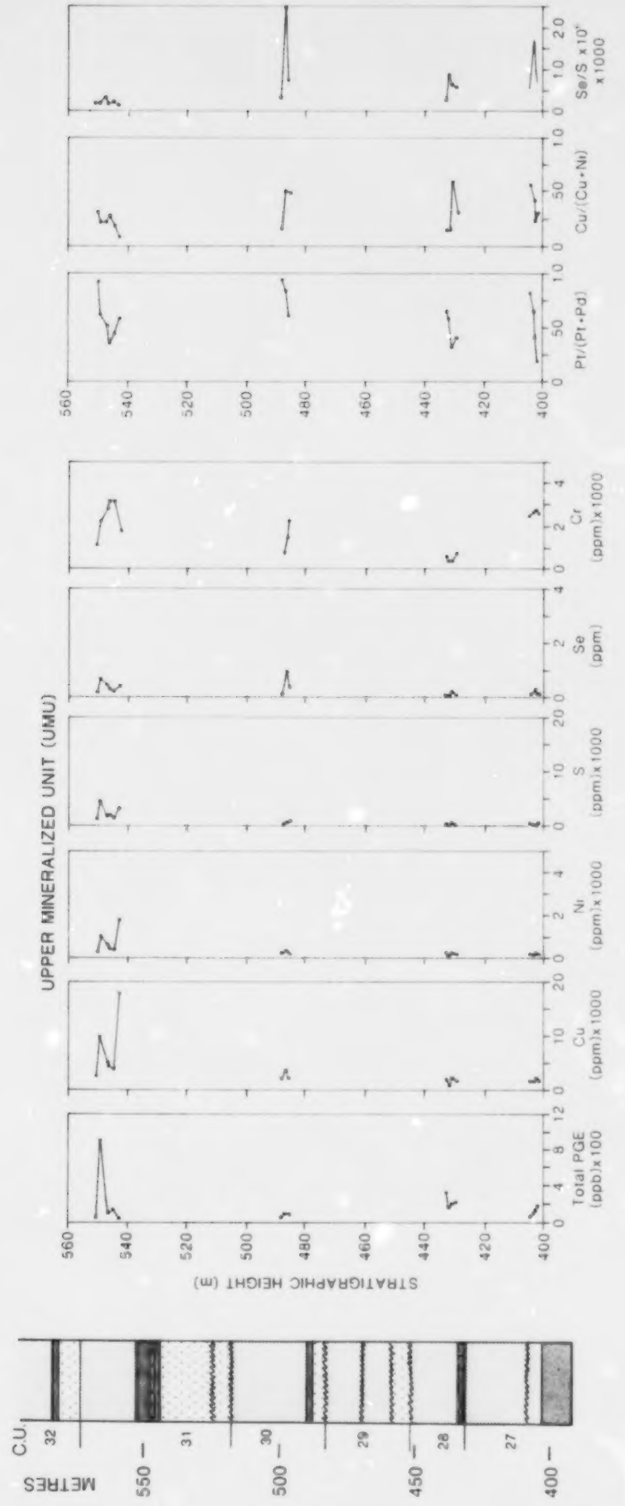


Figure 4C. Stratigraphic distribution of PGE concentrations and associated elements in the Upper Mineralized Unit.

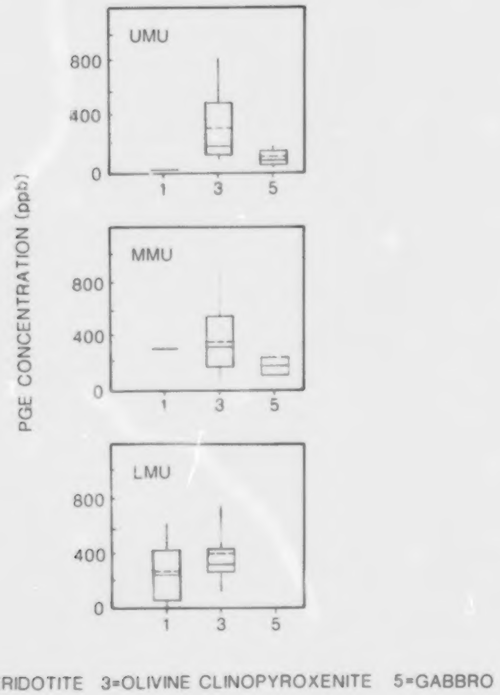
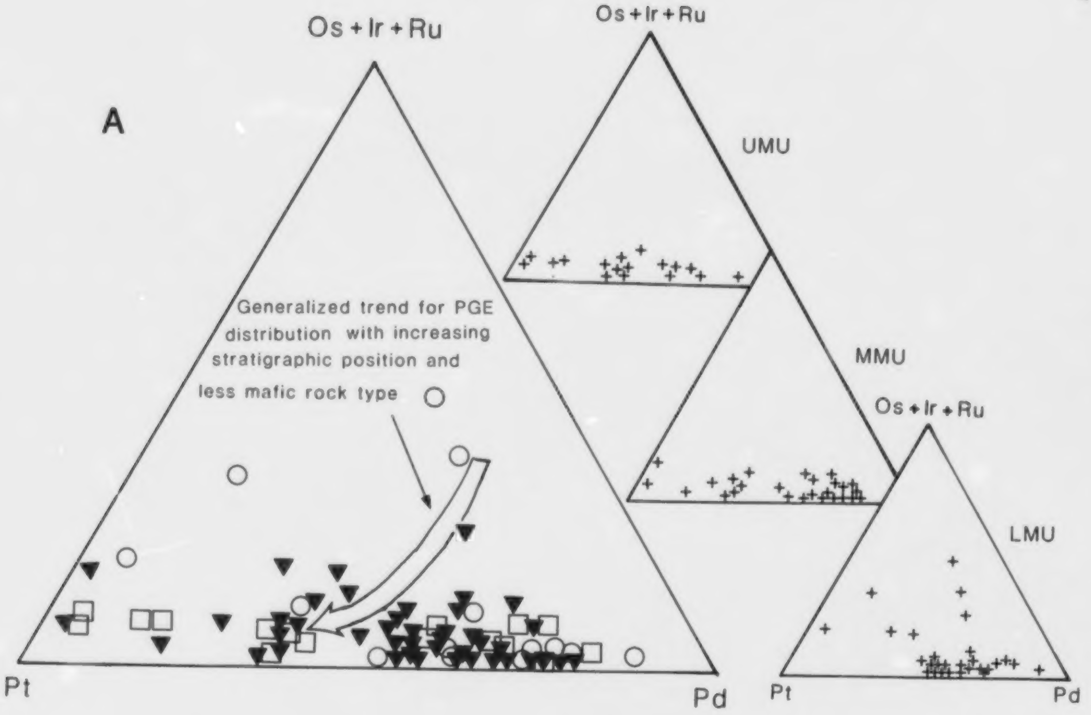


Figure 5. Box and Whisker Plot illustrating the distribution of total PGE concentrations for the Lower, Middle and Upper Mineralized Units.

SYMBOLS: --- = Average; —— = Median; area inside box = middle 50% of values; Whiskers extend to minimum and maximum values.



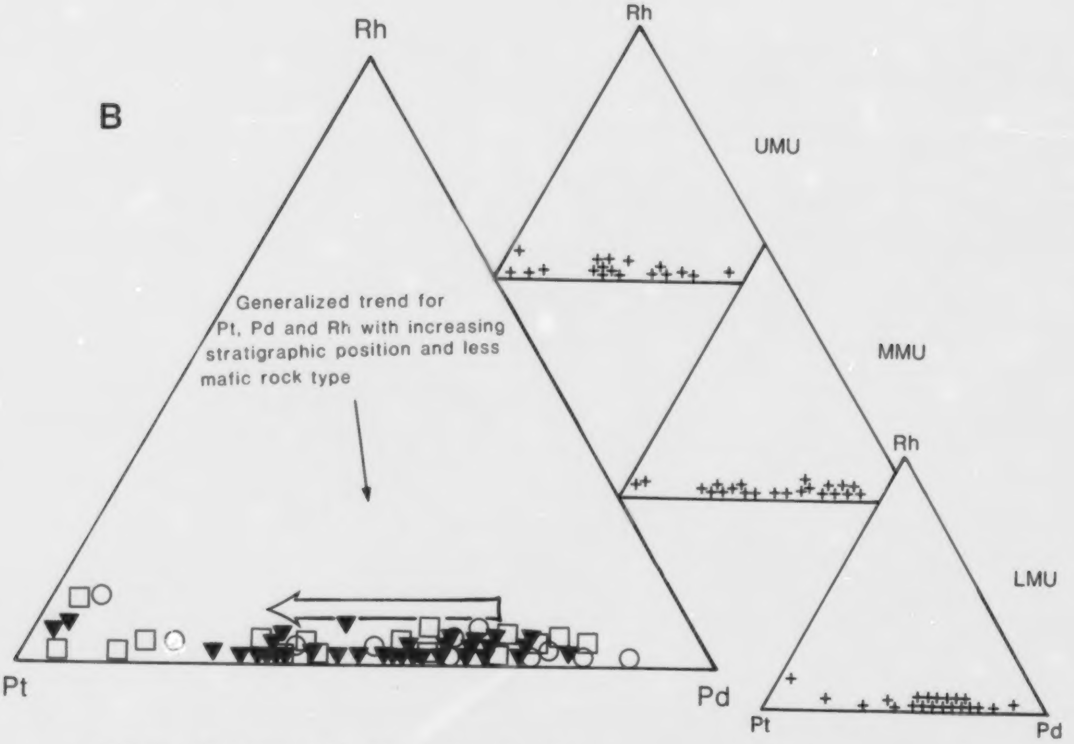


Figure 6A. Variation of Pt, Pd and (Os + Ir + Ru) concentrations among individual mineralized units.

Figure 6B: Variation of Pt, Pd and Rh concentrations among individual mineralized units. (inverted triangles= peridotite, open circles = pyroxenite, open squares = gabbro).

2. Middle Mineralized Unit (MMU - Figure 4B)

In the MMU, PGE, Cu, Se and S abundances again display similar distribution patterns. Profiles of Ni abundances do not correspond as well to the PGE profiles,; however, some Ni peaks do correlate with peaks in PGE abundances. Profiles of Cr abundances do not resemble those of PGE suggesting that distribution of the two are interdependent. Pt/(Pt + Pd) and Cu/(Cu + Ni) profiles do not vary sympathetically; peaks in Pt/(Pt + Pd) commonly correspond to lows in Cu/(Cu + Ni) suggesting that Pt-rich rocks are not necessarily Cu-rich. The Se/S * 10^6 is notably flat. Peak PGE, Cu, S, and Se abundances occur in pyroxenite.

3. Upper Mineralized Unit (UMU - Figure 4C)

In the UMU the relationship between element profiles is not well establised as there are fewer data points; however, it is still evident that peak PGE abundaces positively correlate with peaks in Cu, Ni, S and Se abundances. Pt/(Pt + Pd) and Cu/(Cu + Ni) profiles are not similar. Peak Pt/(Pt + Pd) values often correspond to low Cu/(Cu + Ni) values. The Se/S*10^6 values fluctuate, with some peak values corresponding to increases in PGE abundances. Pyroxenite and gabbro host anomalously high PGE abundances.

Statistical analysis was used to further evaluate the geochemical and mineralogical associations of PGE (Table I). There is a moderately positive correlation among total PGE (TPGE) and base metal sulphide elements but a poor correlation with TPGE and S over the entire study interval. Within individaul mineralized units the relationship between PGE and associated elements varies implying PGE affiliation among the LMU, MMU and UMU differs.

1. Lower Mineralized Unit (Table IB)

Within the LMU, Rh, Pt and Pd are strongly intercorrelated. TPGE positvely correlates with Se and Cu but not S or Ni. Pt, Cu and Se are particularly strongly intercorrelated. Pt and Au, and Ni and Ir display a weak affiliation.

2. Middle Mineralized Unit (Table IC)

Within the MMU Rh, Pt and Pd are moderately positively correlated and there is a consistent interdependence of Pt, Pd and Rh with Se, S and Cu. Pt and Au are moderately associated. Ni is moderately positively correlated with Ir, S and Se and is weakly correlated with Pt and Rh.

3. Upper Mineralized Unit (Table ID)

Within the UMU there is a notable lack of correlation between PGE and elements of BMS affiliation and among the PGE themselves. Sulphides in the UMU have been extensively replaced by mgn +/- py assemblages. Redistribution of BMS elements may partially explain the apparent lack of association between BMS elements and PGE concentrations. Cr, which negatively correlated with most elements in the other mineralized units, displays a positive relationship with S and Se.

PGE are associated with elements of BMS affinity in the LMU and MMU but not the UMU. No association between PGE and elements of late magmatic or hydrothermal affinity (ie As, Te, Sb, Bi etc.) or with Cr is evident from the correlation analyses. The positive correlation between PGE and Cu and Se in the LMU and MMU suggest that PGE may be associated with ccp.

Chondrite Normalized Profiles (CNP) for each of the LMU, MMU and the UMU display three distinct internal trends defined by variations in the Pt/(Pt + Pd): These trends display a continuum of low to high PGE concentrations (Figure 7).

i) Positive Pd Profile [Pt/(Pt + Pd) < 0.5]
ii) Plateau Pd Profile [Pt/(Pt + Pd) > 0.5 < 0.7]
iii) Negative Pd Profile [Pt/(Pt + Pd) > 0.7]

CNP reflect the overall trend of Pd depletion with increasing stratigraphic position. The proportion of Positive Pd profiles decreases relative to Plateau and Negative Pd profiles from the LMU through the MMU and the UMU respectively.

The trend of increasing Pt/(Pt + Pd) with stratigraphic height is reflected in the CNP by an increasing proportion of Plateau and Negative Pd Profiles and decreasing proportion of Positive Pd profiles from the LMU to UMU. The shift in CNP relative to the mineralized units and rock type is

TABLE I : CORRELATION COEFFICIENT TABLES* (Based on log normal distribution)

A: Correlation Coefficients: ALL DATA (n = 89)
(At the 95% confidence level, correlation coefficients >0.21 are considered significant).

	TPGE	Ir	Ru	Rh	Pt	Pd	Au	S	Se	Cu	Ni	Cr	Co	Sb
TPGE														
Ir	**.68**													
Ru	.18	.29												
Rh	**.72**	**.66**	.11											
Pt	**.86**	**.69**	.14	**.64**										
Pd	**.89**	**.57**	.21	**.58**	**.59**									
Au	.31	.22	-.08	.30	.46	.11								
S	.39	.48	.25	.30	.32	.35	.23							
Se	**.54**	**.52**	.24	.34	.46	.49	.28	**.90**						
Cu	**.60**	.38	.09	.39	**.55**	**.52**	**.50**	**.67**	**.79**					
Ni	.34	**.54**	.25	.20	.26	.30	-.10	**.79**	**.75**	.38				
Cr	-.17	.07	.17	-.11	-.10	-.16	-.04	.28	.25	-.08	.36			
Co	.40	**.50**	.19	.27	.30	.38	-.06	**.82**	**.76**	.45	**.94**	.25		
Sb	-.09	-.22	.01	-.11	-.18	-.04	-.15	-.21	-.19	-.06	-.18	-.23	-.19	
As	-.15	-.33	-.08	-.18	-.16	-.14	-.09	-.54	-.42	-.28	-.47	-.25	-.46	**.52**

B: Correlation Coefficients: Lower Mineralized Unit (n = 38)
(At the 95% confidence interval, correlation coefficients > 0.33 are considered significant).

	TPGE	Ir	Ru	Rh	Pt	Pd	Au	S	Se	Cu	Ni	Cr	Sb
TPGE													
Ir	.44												
Ru	.15	.26											
Rh	**.75**	.40	.00										
Pt	**.92**	**.60**	.15	**.74**									
Pd	**.95**	.27	.15	**.66**	**.77**								
Au	.33	.29	.16	**.51**	.49	.18							
S	.13	.46	.02	-.09	.17	.04	-.21						
Se	**.60**	**.58**	.09	.26	**.62**	.47	.03	**.75**					
Cu	**.63**	.36	-.08	.45	**.72**	.47	.46	.41	**.68**				
Ni	.20	.49	.08	-.10	.15	.17	-.48	**.80**	**.70**	.16			
Cr	-.33	.13	.11	-.43	-.33	-.34	-.37	.37	.06	-.23	.40		
Sb	.07	.10	.26	.08	.04	.06	.03	.02	.10	.11	.06	.08	
As	.18	.25	.38	.16	.12	.19	-.08	.01	.16	-.12	.22	-.12	**.74**

C: Correlation Coefficients: Middle Mineralized Unit (n = 34)
(At the 95% confidence interval, correlation coefficients > 0.35 are considered significant).

	TPGE	Ir	Ru	Rh	Pt	Pd	Au	S	Se	Cu	Ni	Cr	Sb
TPGE													
Ir	**.89**												
Ru	-.16	-.23											
Rh	**.76**	**.75**	-.21										
Pt	**.78**	**.90**	-.29	**.64**									
Pd	**.88**	**.62**	-.03	**.55**	.47								
Au	.46	**.59**	-.39	.33	**.67**	.22							
S	**.56**	**.63**	.05	**.53**	**.62**	.36	.41						
Se	**.65**	**.67**	.01	**.61**	**.61**	**.50**	.42	**.95**					
Cu	**.63**	**.61**	.06	**.56**	**.54**	**.64**	.49	**.75**	**.84**				
Ni	.35	**.52**	-.27	.41	.45	.07	.27	**.60**	**.58**	.27			
Cr	-.38	-.08	-.01	.28	.08	-.56	.07	-.06	-.21	-.47	.15		
Sb	-.04	-.15	.07	-.02	-.34	.05	-.16	-.17	-.13	-.10	.01	-.25	
As	-.28	-.37	.09	-.25	-.48	-.13	-.20	-.37	-.38	-.22	-.28	-.34	**.65**

D: Correlation Coefficients: Upper Mineralized Unit (n = 17)
(At the 95% confidence interval, correlation coefficients > 0.48 are considered significant).

	TPGE	Ir	Ru	Rh	Pt	Pd	Au	S	Se	Cu	Ni	Cr	Sb
TPGE													
Ir	**.86**												
Ru	**.67**	**.80**											
Rh	**.70**	**.74**	**.71**										
Pt	**.82**	**.88**	**.67**	**.62**									
Pd	**.83**	**.62**	**.50**	.47	.43								
Au	-.09	.01	.05	-.08	.17	-.38							
S	.06	.17	.48	.01	.06	.09	.25						
Se	.01	.10	.41	-.18	-.01	.12	.39	**.79**					
Cu	-.03	-.01	.23	-.30	-.03	.02	.44	**.64**	**.84**				
Ni	.05	.17	.45	.05	.01	.07	.07	**.88**	**.66**	**.50**			
Cr	-.14	-.09	.28	.06	-.22	.03	.36	**.57**	**.63**	.37	.38		
Sb	-.21	-.30	-.33	-.26	-.39	.04	-.59	-.15	-.17	.02	-.05	-.34	
As	-.15	-.20	-.24	-.09	.40	.13	.15	-.56	-.20	.08	-.55	-.20	.04

*Correlation coefficients > .50 are illustrated in bold type

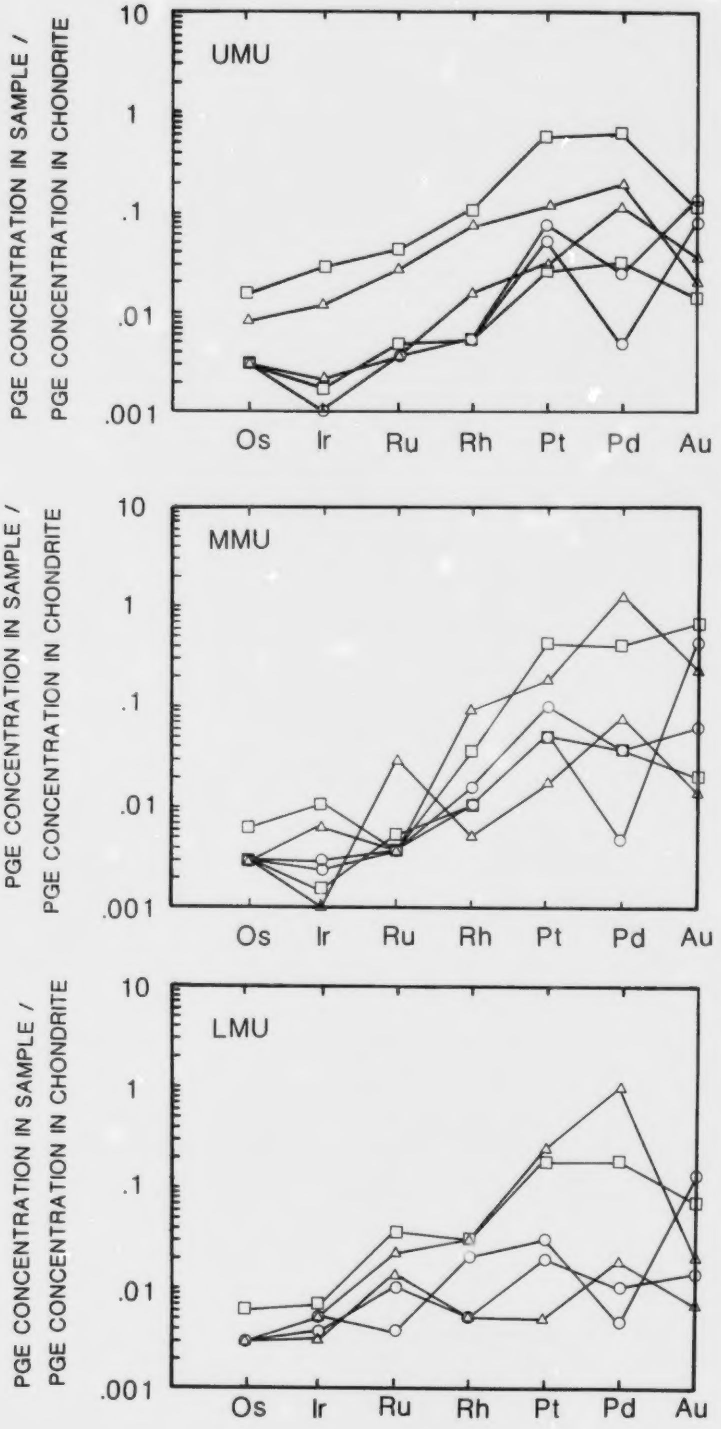


Figure 7. Range of chondrite normalized negative, plateau and positive Pd profiles for the Lower, Middle and Upper Mineralized Units.

Open circle = range of negative Pd profile
Open square = range of plateau Pd profile
Open triangle = range of positove Pd profile

graphically presented in Figure 8. Peridotite and pyroxenite exhibit Positive and Plateau profiles ($Pt/(Pt + Pd < 0.7)$; gabbroic rocks typically exhibit Negative Pd profiles ($Pt/(Pt + Pd > 0.7)$.

Erratic fluctuations of Pt + Pd/ (Os + Ir + Ru) and Pd/Ir ratios may be attributed to a combination of the low abundances of Os, Ir and Ru, and incorporation of available Os, Ir and Ru as inclusions into chromite during crystallization.

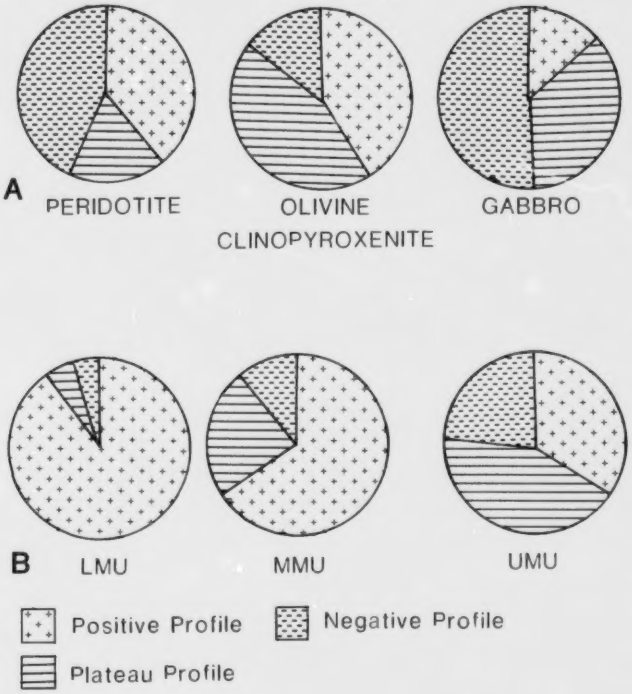


Figure 8A. Distribution of chondrite normalized profiles with rock type
Figure 8B. Distribution of chondrite normalized profiles with mineralized units.

SULPHUR ISOTOPES

The S isotopic composition of sulphides was determined to help interpret the provenance of S in Fox River Sill sulphides. All ^{34}S values lie well outside the mantle range (+1‰, Shima et al., 1963; +3 to -3, Ohmoto and Rye, 1987), ranging from +9.2 to +17.4. Samples with the heaviest ^{34}S signature are from the LCLZ. Generally the ^{34}S progressively decreases with increasing stratigraphic height (Figure 9). The presence of consistent, anomalously heavy ^{34}S values places constraints on the provenance of S in the Fox River Sill. All ^{34}S analyses lie well outside the mantle range, and are similar to those of Noril'sk, Duluth and Muskox where contamination of the magma by crustal S has occurred (Sasaki 1969; Liebenberg 1970; Mainwaring and Naldrett 1976). Contamination of the Fox River Sill magma by heavy ^{34}S may have occurred by (i) bulk assimilation of crustal S, with inherent heavy ^{34}S, during intrusion of numerous magma pulses and/or (ii) reaction of the Fox River Sill magma with a ^{34}S-enriched fluid phase.

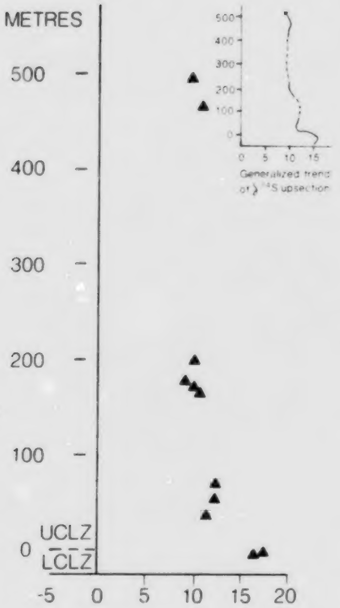


FIGURE **9** δ^{34}S values with stratigraphic position

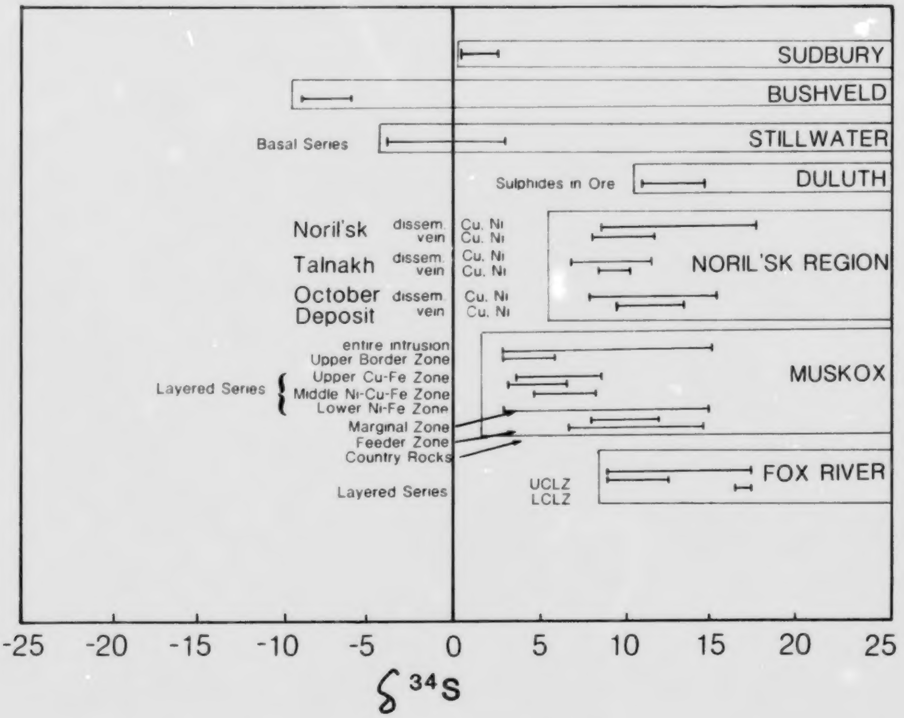


Figure 10. Range of sulphur isotopes within the Fox River Sill and other mafic-ultramafic intrusions.

The anomalously heavy ^{34}S of the LCLZ, although spatially located only 55 m from and UCLZ sample with notably lighter ^{34}S, implies an abrupt change in the source of S in the UCLZ compared to that of the LCLZ. The trend from heavy ^{34}S values toward slightly lighter values with increasing stratigraphic height (Figure 10) has been observed in the Muskox, Bushveld, and Duluth Intrusions.

A MODEL FOR PLATINUM GROUP ELEMENT DISTRIBUTION IN THE FOX RIVER SILL

Fox River Sill magmas, which had assimilated crustal sulphur, were emplaced into the Fox River Belt. Sulphur saturation was not immediately attained, and heavy sulphur from the crust was thoroughly homogenized with juvenile sulphur in the magma chamber. Interaction of the magma with a ^{34}S-enriched fluid may have contributed to the heavy S values. During crystallization of the magma, the PGE partitioned; Os, Ir and Ru may have formed alloys, whereas Pt, Pd and Rh were concentrated in the evolved liquid phase of the magma. Upon sulphur saturation, Pt, Pd and Rh were dissolved into the sulphide liquid which upon cooling precipitated monosulphide solid solution. On further cooling, pyrrhotite, pentlandite and chalcopyrite exsolved from the monosulphide solid solution to form primary sulphide assemblages commonly observed as polymineralic grains. Periodic injections of new magma displaced and mixed with fractionated magma to form the numerous cyclic units observed. Compaction of the cumulate pile resulted in migration of volatile-rich, PGE-bearing intercumulus material. High PGE abundances in coarse-grained to pegmatitic sulphide and amphibole-bearing pyroxenite indicates that pyroxenite preferentially acted as sinks for the migrating deuteric fluids and PGE abundances in the pyroxenite were subsequently upgraded. Local mobilization and redistribution of sulphides, as seen by the sulphide-silicate replacement and recrystallization textures, may have resulted in a geochemical separation of PGE and base metal sulphide elements. This is reflected by only moderate correlation among these elements.

From the above observations exploration targets for PGE concentrations in the Fox River Sill are contained in thin, more highly differentiated cyclic units of the Upper Central Layered Zone, as suggested by Scoates and Eckstrand (1986)

More specifically, elevated PGE abundances are preferentially associated with coarse-grained, copper and sulphide-bearing intervals that exhibit evidence of deuteric alteration. The low tenor of PGE in dunite and in zones of fault breccia preclude these intervals as targets of PGE concentration.

Macdonald (1987) noted that where sulphur saturation has been attained as a result of assimilation of crustal sulphur, resultant PGE concentrations tend to be located at the contact between the intrusion and the country rocks (Sudbury, Noril'sk). Watkinson and Dahl (1988) have suggested that fluids released from assimilated country rock xenoliths mobilize Cu, Ag, Pb, Pt and Rh from the intruded rocks. These elements precipitate when the fluid reacts with pyrrhotite and magnetite. These observations suggest that another exploration target for PGE concentration in the Fox River Sill would be in sulphide and oxide-bearing rocks of the Marginal Series where the Fox River Sill is in contact with the country rocks, particularly where there is evidence of direct assimilation of the country rocks.

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STRUCTURAL GEOLOGY AND DEFORMATIONAL HISTORY OF THE THOMPSON NICKEL ORE BODIES AND ENVIRONS THOMPSON, MANITOBA

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INTRODUCTION

This study of the structural geology of the Thompson nickel deposits was conceived in 1985 when it became clear that Inco's new open pit mine at Thompson would provide new and exceptional exposures of this important and structurally complex deposit. Consequently the Geological Survey of Canada, in consultation with Inco Limited and the Manitoba Geological Services Branch, initiated the project under the terms of the Manitoba Mineral Development Agreement as a contract (Ph.D. thesis) study under the supervision of Paul Williams at the University of New Brunswick . The objectives were to study the structure of the Thompson nickel deposits in order to determine their structural and metamorphic history, and if possible to identify new exploration targets. The original contract period was intended to fund two field seasons (1986, -87). However as studies progressed, funding was extended to include the 1988 field season in order to document obviously important additional features.

SCOPE OF THE PROJECT

The project is divided into nine thematic studies: 1) structural, and 2) metamorphic history of the Thompson nickel sulphide ore body and its gelogical environment, taking advantage of the unique but temporary exposures created in Inco's recently developed Thompson Open Pit. To support this study and to test evolving models, many additional areas in the Thompson Nickel Belt (TNB) were visited and studied. Key areas selected for further detailed work included Pipe II Open Pit, Ospwagan Lake, Mystery Lake and Sipiwesk Lake. The first three areas together with the Thompson Mine area form a geological entity, and provide key exposures of the Early Proterozoic Ospwagan Group (Bleeker and Macek, 1988a). This Pipe-Thompson-Mystery Lake region contains the most important nickel deposits, and shows many faults related to the western boundary of the belt. The Sipiwesk Lake area provides a detailed view of the eastern boundary of the TNB and its relationship to the adjoining Pikwitonei granulite of the Archean foreland.

The new structural-metamorphic data, as well as clarifying many geometrical and metamorphic aspects, has resulted in: 3) a detailed tectonic model for the TNB (Bleeker, 1988). 4) Geochronological work is being carried out to provide a time scale for the tectonic model and to answer such fundamental questions as the age of the Ospwagan Group. This work involves two approaches. In the first, about 10 samples collected in this study are being dated in collaboration with the GSC and Royal Ontario Museum (ROM) geochronological laboratories. The second approach relates to several precise U/Pb dates that have been determined over the last three years in a separate study at ROM (N. Machado, personal communication). Some of these reported dates lack detailed structural background. Therefore appropriate structural studies were carried out to allow better interpretation of these reported dates.

Mapping of Thompson Open Pit, Ospwagan Lake, Mystery Lake and especially Pipe II Open Pit (Bleeker and Macek, 1988b) has resulted in: 5) a detailed lithostratigraphy for the Ospwagan Group (Bleeker and Macek, 1988a; Bleeker and Macek, in preparation). Several key lithologic units, hitherto unknown or inadequately defined in the TNB, were recognized, including a basal conglomerate, a quartz-phyric rhyolite, and widespread sulphide facies iron formation.

6) Many additional mafic dykes have been encountered in mapping in the Pipe-Thompson region, and are believed to be part of the 1883 Ma Molson dyke swarm that is known to the east in the Archean foreland. Chemical analyses are in progress to test this correlation. The importance of these dykes is that, though they clearly have been folded, they can be demonstrated to postdate the F1 nappe emplacement in the TNB. This interpretation has several important implications. First, the F1 event is older than 1883 Ma. Secondly it constrains the structural timing of the Molson dyke swarm in a new tectonic context. Finally, it refutes the hypothesis that the nickel ore related ultramafic bodies (pre-F1) and the mafic/ultramafic Molson dykes belong to the same magmatic event.

Mylonites and pseudotachylite-generating brittle faults along the western margin of the TNB have been selected for a further thematic structural study (7) (Bleeker and Williams, in preparation). The mylonites are of interest because they provide overwhelming evidence for ductile reverse faulting, while at the same time the TNB has well-defined characteristics of a major sinistral strike-slip fault zone. A second system of pseudotachylite-generating fault zones has been defined in the Archean foreland, stretching from central Sipiwesk Lake to Cross Lake (pseudotachylites at Cross Lake were shown to the author by T. Corkery, Manitoba GSB). These extensive pseudotachylites are pre-Molson in age and thus confirm that the Pikwitonei granulites were essentially cold and at shallow crustal levels prior to Molson dyke intrusion. Preliminary paleomagnetic work (8) in collaboration with Ken Buchan at the GSC suggests that these pseudotachylites may be of Late Kenoran age.

The last thematic study consists of: 9) detailed mapping and sampling of the Thompson nickel sulphide ore body and spatially (and probably genetically) related sulphide facies iron formation ("barren sulphides"), both in the open pit and underground. The aim of this study is to recognize distinct sulphide types (e.g., nickeliferous magmatic sulphides, non-nickeliferous sulphide iron formation, metasomatic hybrid sulphides) based on chemical, structural, textural and mineralogical attributes. To date, a wide variety of ore types has been recognized and described. In addition associated sulphide facies iron formation, which generally consists of highly graphitic schist with either disseminated or 1-100 cm thick massive pyrrhotite bands, have been carefully documented.

Some of the nine thematic studies will not be completed within the term of the 1984-89 Mineral Development Agreement. They were started because of the unique opportunity to map and sample the temporary exposures provided by the mining operation in the Thompson Open Pit, and will be pursued as opportunity permits.

SUMMARY OF SELECTED RESULTS

One of the most important results to date is the identification of nappes in the structure of the Thompson Nickel Belt. It was previously recognized that the Belt consisted of Archean granulite gneisses (part of the Pikwitonei terrane) and infolded enclaves of Proterozoic supracrustal rocks (Ospwagan Group), all transposed into north-northeasterly Hudsonian trends (1.8 Ga), and generally re-equilibrated to amphibolite metamorphic facies.

The Archean origin of the basement gneisses is isotopically well established (Cranstone and Turek, 1976; N. Machado, personal communication). Along the west shore of Ospwagan Lake (locality A, Figure 1), the basement gneisses are observed to contain palimpsest Kenoran structures. These gneisses also show polymetamorphic textures in which Kenoran granulite facies textures have been overprinted by Hudsonian middle amphibolite facies assemblages. Although this basement gneiss west of Ospwagan Lake is affected by the late, tight upright folding and subsequent mylonitization, the preservation in it of Kenoran features suggested that it could represent an Archean basement window. During the present study, it became clear that this gneiss locality is actually part of the less deformed lower limb of a regional F1 nappe structure (Figure 2) An important attribute of this "lower limb gneiss domain" is that the gneisses are still largely grayish in color and tonalitic-amphibolitic in composition, i.e. the general compositional spectrum of the Archean foreland.

In contrast, the basement gneisses of the Thompson Mine area are structurally completely reworked and metasomatically transformed. The complete Hudsonian deformational history, i.e., F1, F2,..., can be demonstrated in these gneisses. They are streaked with pink neosomes, and contain abundant K-feldspar. Microcline-rich pegmatites are ubiquitous. All these observations support the structural evidence that the Thompson Mine area is situated on the highly deformed overturned limb of the regional F1 nappe (Fig. 1 to 4). During the prograde metamorphic event, these gneisses lay above the metasedimentary wedge and apparently were metasomatized by the flux of potash-rich metamorphic fluids that were expelled from the underlying metasediments (Figures 3 and 4). This contrasts with the west Ospwagan gneisses which were in the lower limb of the nappe and were thus not so strongly deformed or metasomatized.

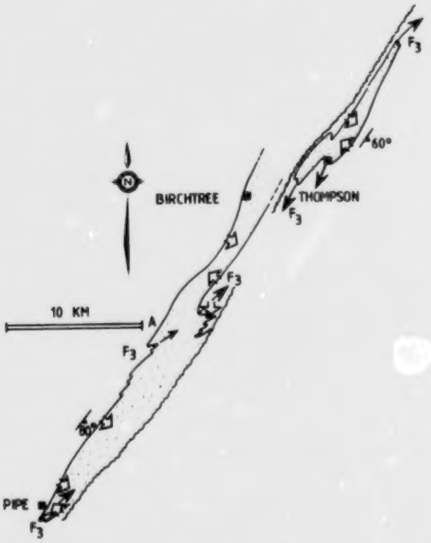

Figure 1: Simplified geological sketch map of the Pipe-Thompson region, showing the distribution of highly deformed Ospwagan group supracrustal rocks (dotted pattern) surrounded by basement gneiss (no pattern). Open arrows indicate the younging directions at various localities. Note that the Thompson structure is a downward facing F3 antiform. Locality "A" is west Ospwagan Lake.

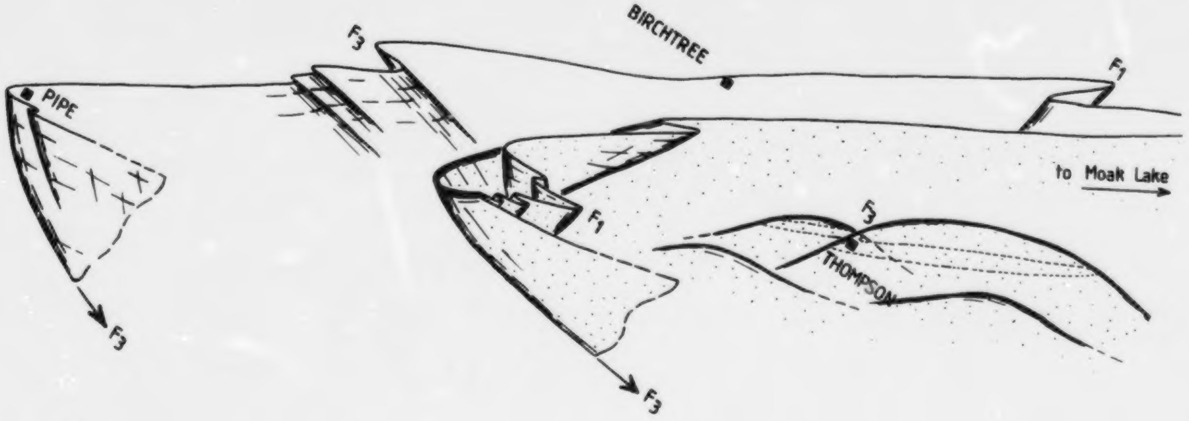

Figure 2: Sketch of the 3-dimensional structure of the Pipe-Thompson region, looking ± 35° down toward the north (compare with Fig. 1 for scale). Two limbs of a large nappe structure can be demonstrated: the Pipe-Birchtree lower limb and the Manasan Quarry-Thompson overturned limb (dotted pattern). This downward facing limb shows much higher strain than the better preserved lower limb, a strain pattern typical of large asymmetric nappes/recumbent folds. Pinching out of the metasedimentary belt around Moak Lake (upper right, off the page) is interpreted to be due to an F1 hinge. The Burntwood fault which truncates the structure is not shown.

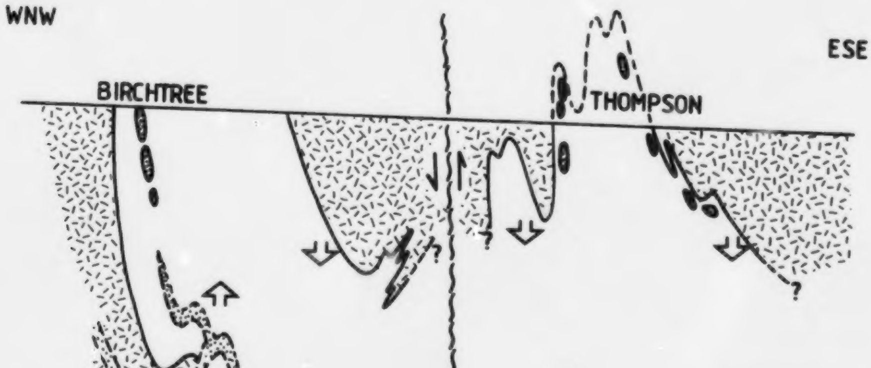

Figure 3: A conceptual projected cross-section through the F1 nappe of the Pipe-Thompson region, showing the upward facing lower limb and the downward facing Thompson limb. Note (1) the contrast in strain between the lower and overturned limb, indicated qualitatively by the extent of boudinage of the Ospwagan-Pipe ultramafite versus the more widely separated boudins of the Thompson ultramafite. (2) The structure furthermore requires that the lower limb must be present at deeper levels below Thompson. The tight, high amplitude upright folds are F3 structures. Note also that (3) because the overturned Thompson limb overlies the metasediments, it has experienced fluxing by metamorphic fluids derived from the sediments.

It is important to note that with +/-3 km shallower erosion level the complete Thompson structure would have been removed. Still, based on the structural and metamorphic characteristics described above, the gneisses at Thompson could have been diagnosed as overlying an Ospwagan Group metasedimentary package. Similar gneiss domains with many of the above chatracteristics can be identified in the Thompson Nickel Belt.

Figures 3 and 4 indicate the necessary existence of a deep, lower, upright-facing F1 limb that contains the Pipe and Birchtree deposits. Large sections of the lower and the short overturned upper limb of the F1 nappe are now sufficiently documented (Figure 2), but we do not yet know the vergence and hinge location of the refolded nappe. It is suggested that pinching out of the Ospwagan Group metasedimentary belt around Moak Lake 30 km northeast of Thompson represents an extremely attenuated F1 hinge. The original F1 vergence probably had a large southward component (e.g., as in Figure 4), and the overall interference pattern between the F1 nappe and F3 folding is probably a large mushroom-like structure. The correct characterization of the large scale structural patterns resulting from refolding is of considerable importance because it may provide new insight into the possible location of previously unsuspected Ospwagan Group and contained nickel deposits. Determination of the F1 hinge location is also of significance, as it should limit the northward extent (below reworked gneisses) of the Thompson mine lithological package.

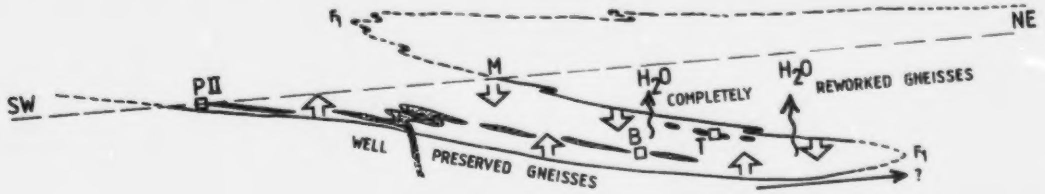

Figure 4: Simplified longitudinal section of the Pipe-Thompson region, showing a cross-section through the F1 nappe. This section is subparallel to the axial plane of the intense F3 structures. Localites are indicated as follows: Thompson (T), Manasan Quarry (M), Birchtree (B) and Pipe II (PII). Younging directions are indicated by the open arrows. The northward extent of the Thompson Mine lithological package (arrow with question mark) below completely reworked gneisses is controlled by the F1 hinge, whose exact location is not yet known.

ACKNOWLEDGEMENTS

This study has been carried out under the thesis supervision of Professor Paul Williams, and the project supervision of C. Van Staal and O.R. Eckstrand of the Geological Survey of Canada. Access to the Thompson Open Pit mine and underground workings, to diamond drill core and to mine records were freely provided by INCO Limited, without which the study would not have been possible. Both Manitoba Geological Services Branch (GSB) and INCO Limited generously provided logistical support. I am particularly indebted to Joseph Macek of the Manitoba GSB for allowing me to use his aerial photographs of the Pipe Open Pit mine, and for his generous support and interest.

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AEROMAGNETIC TOTAL FIELD, VERTICAL GRADIENT, VLF-EM AND TIME DOMAIN-EM SURVEYS IN MANITOBA AND SASKATCHEWAN

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INTRODUCTION

Under the 1984-89 Canada-Manitoba and Canada-Saskatchewan Mineral Development Agreements (MDA's) twelve aeromagnetic total field, vertical gradient and VLF-EM or time domain electromagnetic surveys were completed by contractors on behalf of the Geological Survey of Canada in Manitoba and Saskatchewan (Figure 1).

A total of 78,109 km were flown by Kenting Earth Sciences Limited and Geoterrex Limited of Ottawa in ten survey areas in Manitoba and two in Saskatchewan (Table 1).

The overall objective of these airborne geophysical surveys was to provide accurate, high quality and the most detailed systematic magnetic coverage possible in areas deemed to have economic potential for gold and base metal exploration. The geophysical data compiled from these surveys should serve as an important mapping tool to be used in conjunction with parallel conventional detailed geologic and geochemical mapping programs.

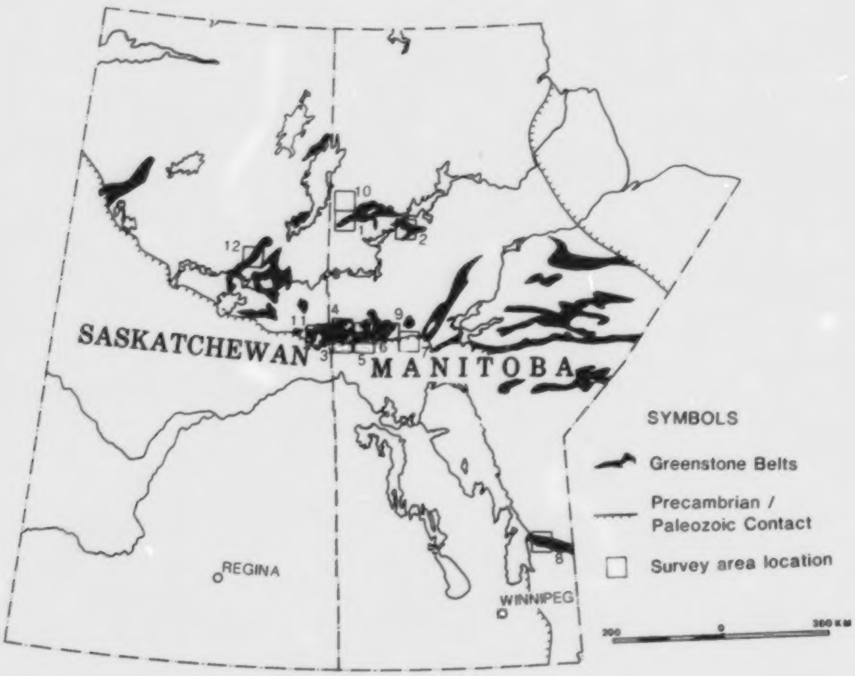

Figure 1. Distribution of greenstone belts in Manitoba and Saskatchewan. Numbered location of survey areas: 1. Lynn Lake SW, 2. Rusty Lake, 3. Flin Flon-Root Lake, 4. Nokomis-Sheridon-Elbow Lake, 5. Moose Lake North, 6. Moose Lake South, 7. Hargrave River, 8. Rice Lake, 9. Snow Lake, 10. Lynn Lake NW, 11. Amisk Lake, 12. Waddy Lake.

TABLE 1.

Aeromagnetic Surveys under Canada-Manitoba MDA Program (1984-1989)

Survey	Type	km	Line Spacing	Altitude	NTS Area Coverage
Lynn Lake SW (Dunphy Lake) (1984-85)	Aeromagnetic Total Field Gradiometer VLF	5,267	300 m	150 Radar	64C/11,12,14
Rusty Lake (Leaf Rapids) (1984-85)	Aeromagnetic Total Field Gradiometer VLF	5,239	300 m	150 Radar	64B/5,6,11,12
Flin Flon-Root Lake (Namew) (1985-86)	Aeromagnetic Total Field Gradiometer VLF	7,884	300 m	150 Radar	63K/3,4,5,6,12,13
Nokomis-Sherridon and Elbow Lake (1985-86)	Aeromagnetic Total Field Gradiometer VLF	6,887	300 m	150 Radar	63K/15,16 63N/1,2
Moose Lake North (1985-86)	Aeromagnetic Total Field Gradiometer VLF	2,289	300 m	150 Radar	63K/7,8
Moose Lake South (1986-87)	Aeromagnetic Total Field Gradiometer VLF	5,654	300 m	150 Radar	63K/1,2
Hargrave River (1986-87)	Aeromagnetic Total Field Gradiometer VLF	8,200	300 m	150 Radar	63J/6,7,10,11
Rice Lake (Bissett) (1986-87)	Aeromagnetic Total Field Gradiometer VLF	5,275	300 m	150 Radar	52L/13 62M/14
Snow Lake (1988-89)	Aeromagnetic Total Field Gradiometer VLF	8,180	300 m	150 Radar	63J/13 63K/15/16
Lynn Lake NW (McMillan Lake) (1988-89)	Aeromagnetic Total Field Electromagnetic	4,907	200 m	120 Radar	64C/13,14

Aeromagnetic Surveys under Canada-Saskatchewan MDA Program (1984-1989)

Survey	Type	km	Line Spacing	Altitude	NTS Area Coverage
Amisk Lake (Flin Flon) (1985-86)	Aeromagnetic Total Field Gradiometer VLF	18,787	300 m	150 Radar	63K/4,5,12,13 63L/1,8,9,10,16
Waddy Lake (1985-86)	Aeromagnetic Total Field Gradiometer VLF	4,779	300 m	150 Radar	64D/3,4,5,6 74A/1,8

TOTAL SURVEY LINE KILOMETRES: 78,109

The surveys selected by the Manitoba Department of Energy and Mines in consultation with the exploration and mining industry and the Geological Survey of Canada focused on the Archean volcanics and metasediments of the Lynn Lake, Leaf Rapids, Rice Lake and Flin Flon-Snow Lake greenstone belts partly extending north over the Kisseynew Gneiss Complex and on the sub-Phanerozoic intrusives east and west of the Cormorant Lake area (Figure 1).

In Saskatchewan, the aeromagnetic survey of the Flin Flon and Kisseynew Domains was extended west from the Manitoba-Saskatchewan provincial boundary to the Hanson Lake Block. This survey included coverage of the Paleozoic carbonate sediments and underlying Precambrian basement rocks as far south as 56°00' N latitude. A smaller survey was also flown in the Waddy Lake area in the Central Metavolcanic Belt of the La Ronge Domain.

INSTRUMENTATION

The majority of these survey areas were flown in the gradiometer mode by Kenting Earth Sciences Limited with a Piper Navajo aircraft, equipped with an optically pumped cesium vapour Varian magnetometer and a Herz Industries Totem 2A VLF receiver. Digital data acquisition was carried out by a Kenting KDSS-5 dual cassette recording system, recorded at a rate of 4 samples per second.

The Lynn Lake NW (McMillan Lake) survey in Manitoba was flown with a CASA twin turbo prop STOL aircraft by Geoterrex Limited with the Geotem Time Domain Electromagnetic system. The aircraft was also equipped with a Varian single-cell cesium vapour magnetometer. The sample rate for the magnetometer was 1 per second while the recording of electromagnetic data was set to 6 per second. All data fields in this survey were recorded by the Geoterrex MADACS Digital Acquisition System.

SURVEY SPECIFICATIONS

Most survey areas were flown at 300 metres traverse line spacing with a distance of 10 kilometres between control lines. The Lynn Lake NW survey area was flown at a tighter traverse line spacing of 200 metres to insure adequate ground coverage by the electromagnetic system. The survey height was maintained at 150 metres above ground in all vertical gradient surveys and at 120 metres for the Lynn Lake NW aeromagnetic - electromagnetic survey.

PRODUCTS

The aeromagnetic total field, gradiometer, VLF-EM and time domain electromagnetic data were processed and archived as line data and gridded data sets and stored on a series of magnetic tapes in ASCII format.

The total field and gradiometer data were compiled and printed in the form of contoured products at a scale of 1:20,000 on an NTS map sheet base. A special series of conductivity maps in contour form for the McMillan Lake, Manitoba area was also printed at this scale.

In addition, with the exception of the Lynn Lake NW area, total field and gradient gridded data were each printed as multicoloured composite maps at a scale of 1:50,000.

VLF-EM profile data, where available, were printed in reverse on the back of the vertical gradient magnetic map sheets with coincident corner registers in order that the VLF-EM data would be visible through and matched to the gradient data when viewed over a light table.

These printed products are available through the Geological Survey of Canada, Map Sales Office, Ottawa and Calgary. Digital archive magnetic tapes for these areas may also be purchased from the Geophysical Data Centre of the Geological Survey of Canada, Ottawa.

RESULTS

Since their development in the mid-seventies, aeromagnetic vertical gradient surveys have been used in mapping geological structure and lithology. The usefulness of this method lies in the ability to differentiate rock types by discriminating between differing magnetic properties of the rocks and using these characteristics to extend conventionally mapped geology into areas which may either be covered by overburden, under lakes or even below layers of non-magnetic sedimentary rocks.

Precision in the mapping of near surface features with the gradiometer system is an improvement in comparison to standard total field magnetic surveys. While closely spaced, vertically dipping geological units are better resolved, contacts between larger rock units can also be located with accuracy at the zero gradient contour level at higher magnetic latitudes (Hood and Teskey, 1989). The aeromagnetic gradiometer, therefore, was used as the primary survey system in this detailed airborne mapping program.

The use of Time Domain-EM in one area was a desirable option since the bedrock had been reported to be conductive (Hosain, 1981). Other auxiliary instrumentation such as the VLF-EM has been particularly useful in outlining faults and some lineations which exhibit long strike length and which are in many cases non-magnetic.

The following is a brief summary of some of the results obtained by the airborne survey systems in each of the previously named greenstone belts in Manitoba and Saskatchewan.

MANITOBA

LYNN LAKE GREENSTONE BELT

The Lynn Lake Greenstone Belt recently mapped and described by Gilbert et al. (1980) is a domain of metavolcanic, metasedimentary and plutonic rocks of Aphebian age (Clark, 1980). Felsic plutons intrude and separate the greenstones into two separate northeasterly trending belts in the vicinity of Lynn Lake commonly referred to as the Northern and Southern Belts.

Previous to the Canada-Manitoba MDA (1984-1989) program, detailed, high sensitivity aeromagnetic surveys in the area east of Lynn Lake had been initiated by the Geological Survey of Canada with the Queenair gradiometer system, and were completed successfully in 1984. The improved resolution offered by this system and the resulting airborne total field and vertical gradient maps produced from the data had proven to be an invaluable aid in detailed mapping of the area. As a result, surveying of the remaining western portion of the greenstone belt was resumed at the earliest phase of this MDA program.

Lynn Lake - SW Area

The survey of this area of the greenstones from Lynn Lake to Zed Lake covering the Northern Belt and the length of the Southern Belt to the Manitoba-Saskatchewan border was commenced in 1985. Total field and vertical gradient magnetic maps with VLF-EM were released in 1986. Evaluation of the magnetic data clearly demonstrated the usefulness of the vertical gradient map as an aid to mapping stratigraphic units. For example, within the metaconglomerate formation, which lies on the north flank of the Northern Belt near Motriuk Lake (Figures2 and 3A), iron-rich horizons are abundant throughout particular units across a thick stratigraphic sequence. These concentrations of iron within the units produce anomalous magnetic highs which are emphasized on the magnetic vertical gradient maps as narrow, linear bands.

Similarly, mapping of iron formations within the Lynn Lake greenstone belt is significant in exploration for gold. In the Farley Lake area, gold occurs in replacement sulphide pockets in close association with iron formations in a series of volcanic flows and volcaniclastic sediments. This mineralized region is generally referred to as the Agassiz Metallotect. Fedikow (1986) has observed the correlation of vertical gradiometer signatures to a number of these iron formations within the metallotect. The formations have been extended westward (Ferreira, 1986) to Motriuk Lake (Fig.2 and 3; B). Although lack of outcrop further west is a problem, there is some evidence of iron-rich horizons within the volcanogenic sedimentary sequence on the vertical gradient map (Fig.2 and 3; C).

Further to the southwest (Figures 2 and 3D), a broad terrain of metagreywackes, granodiorite and intruded gneissoid magnetite tonalite mapped by Cameron (1980), Gilbert et al, (1980) and McRitchie (1976) as part of the Kisseynew Complex exhibits lengthy, broad, ellipsoidal bands of magnetic highs lying along a northeasterly axis. The banding which reflects compositional variation and magnetite enrichment within the gneissic rocks is emphasized on the vertical gradient map. This feature is comparable to the banded appearance of the gneissic granodiorite intrusives mapped north of Mari Lake, Saskatchewan and also in the Kisseynew Complex, northwest of Flin Flon (Figures 5 and 6).

In the area between the northeastern arm of Eager Lake and Tod Lake, a conglomerate member of the Sickle Group has been recognized previously (Hall et al., 1981) to be an unusually distinct magnetic marker on earlier total field magnetic maps, and thus useful in mapping subsurface sedimentary units. The mapped results of the vertical gradient system have since been able to improve the definition of the same magnetic conglomerate member, showing its folded structure (Figures2 and 3E) in clearer detail than was possible in earlier regional airborne geophysical surveys.

The VLF-EM instrumentation carried onboard the aircraft has been successful in delineating the Sickle Group conglomerate described above as well as other structural features in some areas. The Tod Lake fault (Gilbert et al., 1980) striking northeast from Tod Lake to Dunphy Lake (Figures2 and 3F) is detected by all channels of the VLF-EM system.

Lynn Lake - NW Area

The area from Zed Lake to the Manitoba-Saskatchewan border between 56°45' and 57°00' latitude has remained largely unmapped in detail to date, because more than 600 square kilometres of the surface is blanketed by glacial drift. The most recent mapping by Cameron (1980) reported 'exposures of bedrock are restricted mainly to a few large ridges and to the shorelines of the larger lakes '.

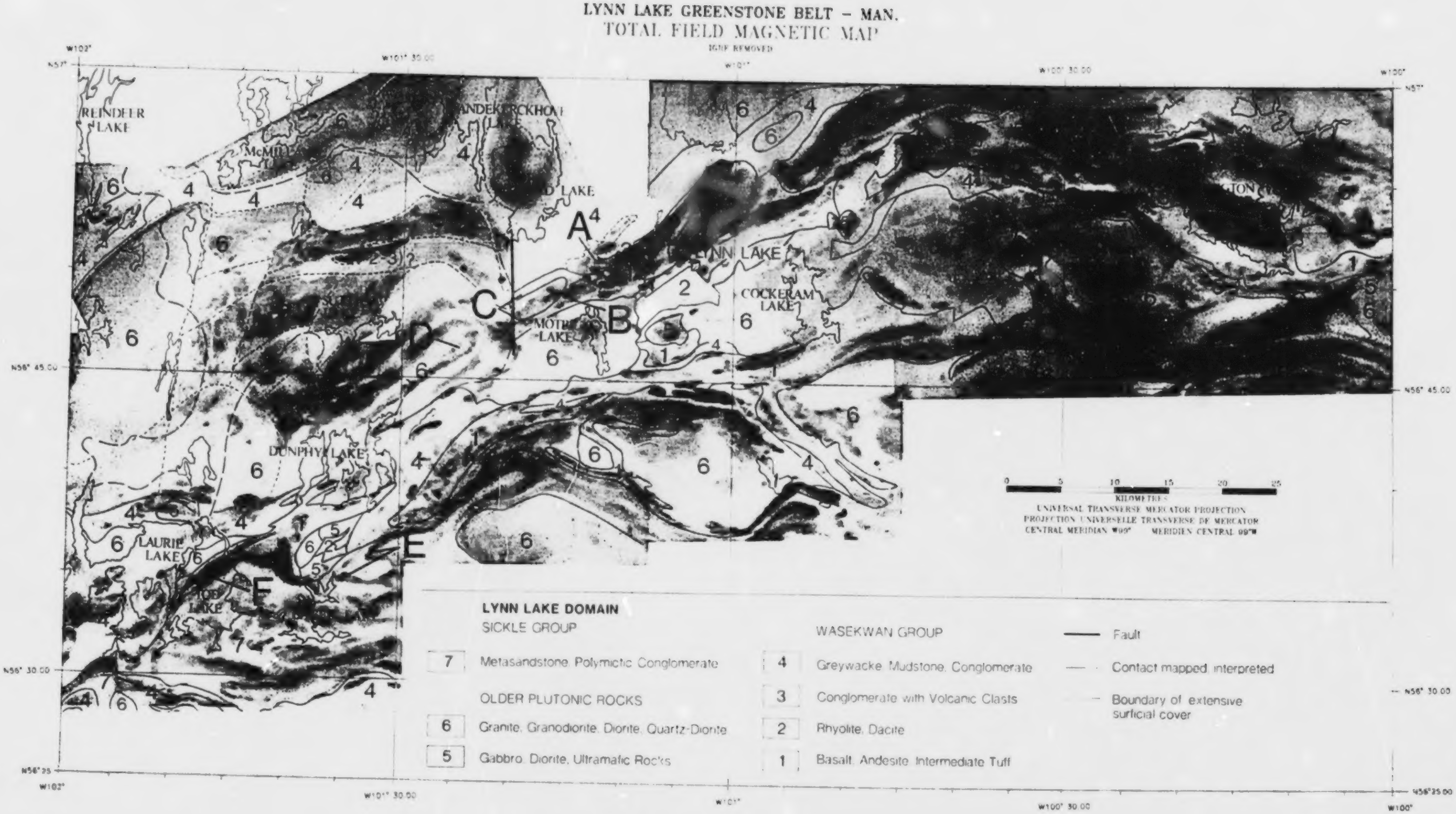
LYNN LAKE GREENSTONE BELT - MAN.
TOTAL FIELD MAGNETIC MAP
IGRF REMOVED
W102°
W101° 30.00
W101°
W100° 30.00
W100°
N57°
N56° 45.00
N56° 30.00
N56°25
REINDEER LAKE
McMILLAN
VANDEKERCKHOVE LAKE
LYNN LAKE
COCKERAM LAKE
MOTRIFF LAKE
DUNPHY LAKE
LAURIE LAKE
TOD LAKE
A
B
C
D
E
F
KILOMETRES
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
PROJECTION UNIVERSELLE TRANSVERSE DE MERCATOR
CENTRAL MERIDIAN W99° MERIDIEN CENTRAL 99°W
0
5
10
15
20
25
LYNN LAKE DOMAIN
SICKLE GROUP
7 Metasandstone, Polymictic Conglomerate
OLDER PLUTONIC ROCKS
6 Granite, Granodiorite, Diorite, Quartz-Diorite
5 Gabbro, Diorite, Ultramafic Rocks
WASEKWAN GROUP
4 Greywacke, Mudstone, Conglomerate
3 Conglomerate with Volcanic Clasts
2 Rhyolite, Dacite
1 Basalt, Andesite, Intermediate Tuff
Fault
Contact mapped, interpreted
Boundary of extensive surficial cover

Figure 2. Lynn Lake, Manitoba - simplified regional geology superimposed on grey scale plot of composite total field aeromagnetic map. Mapped geology after Manitoba Energy and Mines (1986). Areas referenced in text are: (A) iron-rich horizons in metaconglomerate formation; (B and C)iron-rich horizons within volcanoclastic sediments; (D) banding of magnetic highs within gneiss; (E) distinct magnetic marker by member of Sickle Group conglomerate; (F) Tod Lake Fault.

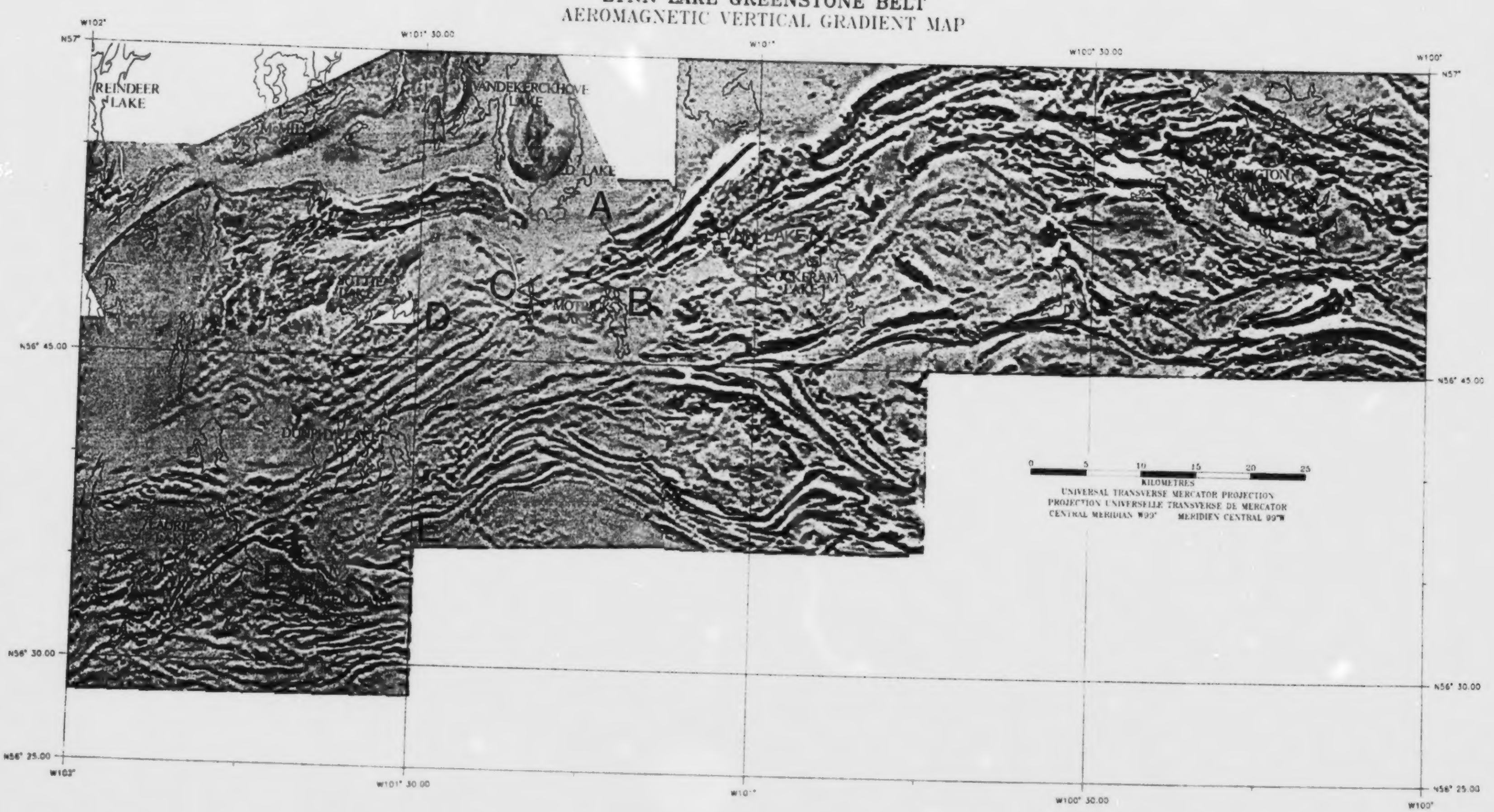
LYNN LAKE GREENSTONE BELT
AEROMAGNETIC VERTICAL GRADIENT MAP
REINDEER LAKE
VANDEKERCKHOVE LAKE
LYNN LAKE
COCKERAM LAKE
A
B
C
D
E
F
0 5 10 15 20 25
KILOMETRES
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
PROJECTION UNIVERSELLE TRANSVERSE DE MERCATOR
CENTRAL MERIDIAN W99° MERIDIEN CENTRAL 99°W
W102°
W101° 30.00
W101°
W100° 30.00
W100°
N57°
N56° 45.00
N56° 30.00
N56° 25.00

Figure 3. Lynn Lake, Manitoba - aeromagnetic vertical gradient composite map reproduced in grey tone. Areas of interest (A,B,C,D,E and F) described in text included for cross reference with figure 2. Survey area east of 101° 00'W was flown previous to this MDA program by the G.S.C. Queenair gradiometer system.

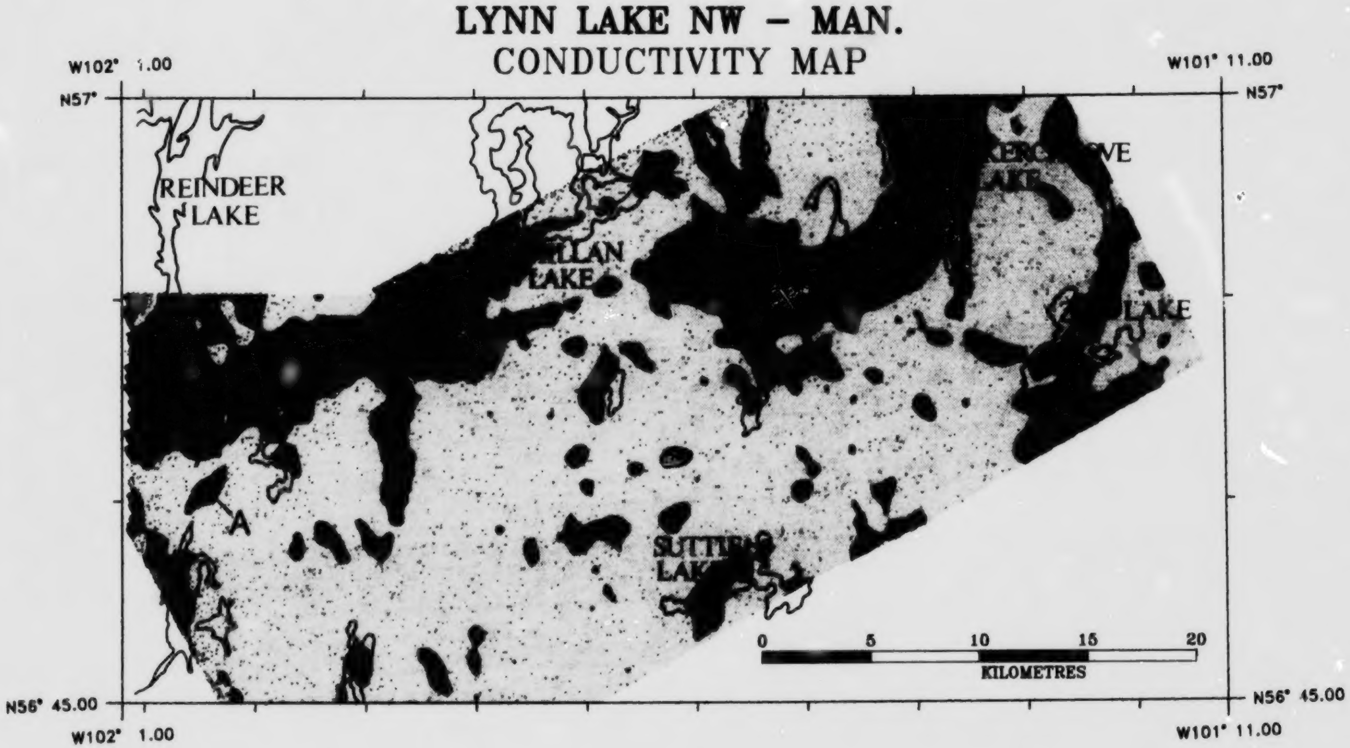
LYNN LAKE NW - MAN.
CONDUCTIVITY MAP
W102° 1.00
W101° 11.00
N57°
N57°
N56° 45.00
N56° 45.00
W102° 1.00
W101° 11.00
REINDEER LAKE
LAKE
LAKE
A
0
5
10
15
20
KILOMETRES

Figure 4. Lynn Lake NW area, Manitoba - Conductivity map in grey tone. Dark areas are indicative of high conductivity. Isolated conductivity high (A) is coincident with a narrow magnetic high striking northeast. Extensive areas of high conductivity are predominantly related to metagreywackes and conglomerates of the Wasekwan Group.

For this detailed survey area, a combined total field magnetic and time domain electromagnetic system was used. Total field magnetic and conductivity contour maps at 1:20,000 scale were produced from the data, and released in 1989.

A gridded conductivity map produced from the electromagnetic data (Figure4) shows that the metagreywackes of Whitesand Bay and Zed Lake are highly conductive and tentatively interpreted to be connected along a broad arc approaching the south shore of McMillan Lake and the southern tip of Vandekerckhove Lake. Approaching Zed Lake, the conductive zone is bifurcated suggesting that the metagreywackes are deflected primarily to the northeast and also to the southeast by a large intrusive body. The southeast arm appears to be segmented and much less conductive. The Zed Lake intrusive, possibly a dioritic mass, is strongly magnetic in conrast to the surrounding weakly magnetic metagreywackeys. These metagreywackes are flanked to the south by non conductive but highly magnetic rocks, possibly the magnetite granite and tonalite described by Cameron (1980b).

A localized, anomalous conductivity high was produced over a long, narrow, northeasterly-striking magnetic high in the Reindeer Lake area, four kilometres south east of the southern tip of Whitesand Bay (Figure 4; loc.A). This conductivity high is also coincident with weakly anomalous geochemical Cu, Zn, Fe lake sediment values recorded by regional geochemical surveys of the Geologic Survey of Canada (GSC-OF999,1983) in the area.

Rusty Lake greenstone belt

Leaf Rapids Area

The gradiometer survey, flown 1985, covers an area bounded on the west by the town of Leaf Rapids, extending east to South Bay and Kinwaw Lake, and from Opachusanau Lake south to Pemichigamau Lake.

The Ruttan Lake copper zinc deposit is the only economic producing mine in the Rusty Lake Greenstone Belt to date. This deposit and other significant sulphide mineralization in the area appear to be confined mostly to metavolcanic and metamorphosed volcaniclastic rocks of the Wasekwan Group.

This vertical gradiometer survey has accurately delineated numerous narrow bands, or multiple bands corresponding to individual magnetic members within these metavolcanic rocks. Large structural features such as the folded sulphide zones described around Rusty Lake by Steeves et al. (1972) are resolved in more detail.

Rice Lake greenstone belt

Bissett Area

In August of 1986, flying commenced in southeastern Manitoba over the Archean Rice Lake volcanic-sedimentary greenstone belt. The results of the survey were published on two maps at 1:50,000 scale covering the Bissett and northeast quadrant of the Manigotagan Lake NTS map sheets.

Widespread gold mineralization within the greenstone belt has long been recognized by prospectors in the area. Over fifteen producing gold deposits have been mined to date. This airborne gradiometer survey was initiated to assist further in the detailed mapping of the area.

On the Bissett map sheet, strong vertical magnetic gradient highs are observed striking east along the Wanipigow-Siderock Fault and the Woods Lake-Hay Creek Faults. The former location of magnetic highs probably correlates with the iron formations within the metasedimentary and metavolcanic rocks of the Rice Lake Group, and the latter to serpentinite described by Scoates (1971). Weaker vertical gradient magnetic highs correlate with metadiabase and gabbro mapped east and west of Rice Lake.

On the Manigotagan sheet, moderately strong vertical gradient highs outline granodiorite and quartz monzanite intrusives around the perimeter of Clearwater, Quesnel and Manigotagan Lakes. Elsewhere, west of the Manigotagan River, multiple alternating bands of high and low magnetic vertical gradients are noted along the layered tonalite gneiss striking southeast suggesting compositional variation within this body.

Flin Flon-Snow Lake greenstone belt and surrounds

A number of aeromagnetic gradiometer surveys have been contracted by the Geological Survey of Canada in the Flin Flon area, centred primarily on the highly prosperous base metal producing areas of the Precambrian greenstone belt and extending north into the Kisseynew Gneiss Complex and south to include the Paleozoic carbonate sediments and underlying Precambrian basement rocks.

The initial phase of airborne geophysical mapping the greenstone belt was carried out with funds provided by the Federal-Provincial Interim Mineral Agreement of 1982-83. As an integral part of Project Cormorant, the airborne mapping program was not only intended to assist in the detailed mapping of the greenstone belt but more significantly, to delineate the extent and the constituents of the Precambrian rocks underlying the Paleozoic sediments and possibly outline new areas which may have potential for base metal deposits. The lay-out of this series of surveys consisted of a twenty kilometre wide area on either side of a baseline corresponding generally with the Paleozoic-Precambrian contact extending from Flin Flon in the west to Hargrave Lake in the east.

Under the new Federal-Provincial Mineral Development Agreement of 1984-1989, the airborne program was expanded to include total field magnetic, gradiometer and VLF-EM mapping in six additional areas, totalling 39,094 line km of survey flying.

The Flin Flon-Root Lake, Moose Lake north, Moose Lake south and Hargrave River surveys covered areas further south and east over the Paleozoic and underlying Precambrian basement rocks not flown in the first phase of the project.

Data from these aeromagnetic surveys were assembled and cross referenced with earlier total field and gradiometer data flown over exposed Precambrian geology, with airborne electromagnetic time domain data, drill core data and earlier geophysical interpretation (Hosain, 1984). Preliminary results were presented by Blair et al. (1987, 1988) outlining magnetic domains which when referenced to drill core data, provide a pseudo-geological map of the rocks below the Paleozoic carbonate sediments. The southward continuation of the metavolcanic rocks below the carbonates, magnetite-poor granitic plutons, gabbroic bodies with layering or zoning and truncations of lineaments indicating faulting are cited in the structural and lithological interpretation.

This survey program was also extended northward to include two additional survey areas to cover the bulk of the metavolcanic rocks in the Kisseynew Gneiss Belt in the Elbow-Nokomis-Snow Lake triangle. They provided additional data to the detailed mapping and metallogenic studies within the Kisseynew belt which were being carried out concurrently under the MDA (1984-89) program.

SASKATCHEWAN

Funding provided for the airborne geophysical phase of the Canada - Saskatchewan MDA (1984-1989) program was directed towards the surveying of two main greenstone belts in east-central Saskatchewan. One selection covered all of the Flin Flon Domain and the Hanson Block which have had a long history of gold and base metal exploration and producing mines. Waddy Lake in the La Ronge Domain was chosen as the second area to be surveyed. This region has recently reached new heights in exploration activity after several significant new occurrences of gold were discovered in the Star Lake - Waddy Lake area in the early eighties.

Amisk Lake Area

The Amisk Lake survey was flown concurrently with the Flin Flon - Root Lake survey in Manitoba. Thus by 1986, the entire length of the Flin Flon greenstone belt from Wekusko Lake, Manitoba to Hanson Lake, Saskatchewan was detailed by aeromagneteic gradiometer/VLF coverage.

Figure 5 shows the general geology of the area superimposed on the total field aeromagnetic map resulting from the survey. In the west, the survey covers the Precambrian Hanson Lake Block consisting of metavolcanic, meta-arkose and granitoid rocks. The Sturgeon-Weir Thrust Fault separates this block from the greenstone belt consisting of metavolcano-sedimentary and plutonic rocks of the Flin Flon Domain and the northern region of metamorphic rocks of the Kisseynew Complex. The rocks in the southern half of the survey area consist of a thin cover of Paleozoic dolomitic sediments which unconformably overly the Precambrian rocks. This boundary marks the edge of the Canadian Precambrian Shield.

On the total field magnetic map, a wide range of magnetic relief is evident. The most significant magnetic highs of several thousand nanoteslas are generally attributed to intrusive rocks of basic to ultrabasic composition, though some notable exceptions exist where granitic intrusives such as the Snake River (Figure 5; loc.A) and Hanson Lake (Figure 5; loc.B) plutons are highly magnetic in the central core of the plutons. The Birch - Table Lake gabbro (Figure 5; loc.C) and the Crater Island granodiorites (Fig.5; loc.D) are delineated as long, narrow, linear magnetic highs and enhanced on the aeromagnetic vertical gradient map (Figure 6).

While lower magnetic relief in the range of 300nT to 500nT is associated with the Missi Group sedimentary sequence, the Amisk Group volcanic flows and volcanoclastic rocks are well bellow this range. This magnetic distinction between the two Groups in the greenstone belt can be applied to map higher grade metamorphic equivalents to the north in the Kisseynew Gneiss Complex (Pearson,1972). Byers (1965) , Pearson (1972) and others have proposed that hornblende gneisses west of Weetago Bay represent metamorphosed volcanic rocks of the Amisk Group, and the interlayered biotite gneisses are equivalent to the Missi sedimentary strata. This interlayered association is demonstrated in the area of Tyrrell Lake (Figures 5 and 6; loc.E) by alternate bands of magnetic highs and lows corresponding respectively to the hornblende and biotite gneisses mapped in the region.

Examples of faulting can be seen in the Kisseynew Complex in the total field and gradiometer maps. A distinct northwesterly lineation extending from Flin Flon is traced by a magnetic low which traces the position of the Ross Lake Fault. In the south central part of the survey area, the Sturgeon-Weir Fault is similarly defined as a magnetic low and can be traced under the Paleozoic sedimentary cover.

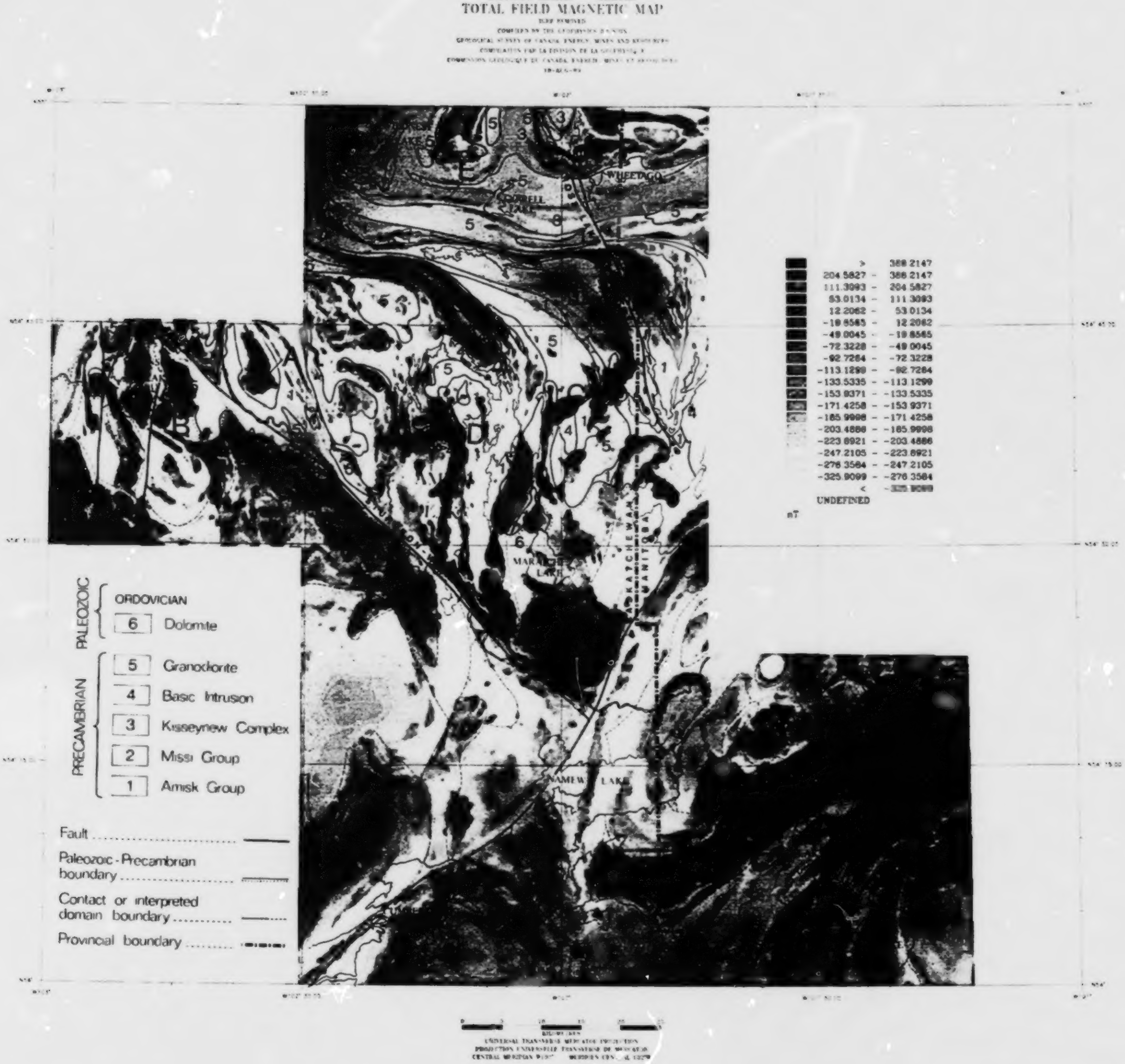
AMISK LAKE - SASK.
TOTAL FIELD MAGNETIC MAP
> 388.2147
204.5827 - 388.2147
111.3093 - 204.5827
53.0134 - 111.3093
12.2062 - 53.0134
-19.8565 - 12.2062
-49.0045 - -19.8565
-72.3228 - -49.0045
-92.7264 - -72.3228
-113.1299 - -92.7264
-133.5335 - -113.1299
-153.9371 - -133.5335
-171.4258 - -153.9371
-185.9998 - -171.4258
-203.4888 - -185.9998
-223.8921 - -203.4888
-247.2105 - -223.8921
-276.3584 - -247.2105
-325.9099 - -276.3584
< -325.9099
UNDEFINED
nT
A
B
C
D
WHEETAGO
MARAGHT LAKE
NAMEW LAKE
SASKATCHEWAN
MANITOBA
PALEOZOIC
ORDOVICIAN
6 Dolomite
PRECAMBRIAN
5 Granodiorite
4 Basic Intrusion
3 Kisseynew Complex
2 Missi Group
1 Amisk Group
Fault
Paleozoic - Precambrian boundary
Contact or interpreted domain boundary
Provincial boundary

Figure 5. Amisk Lake, Saskatchewan - Simplified regional geology map of Precambrian in part after Froese, 1969 and Macdonald, 1981 superimposed on the composite grey tone aeromagnetic total field magnetic map. Sub-Paleozoic domain interpretation after Blair et al., 1988. Areas referenced in text: Snake River and Hanson Lake plutons (A) and (B) with high magnetic core; (C) Birch Lake - Table Lake gabbro; (D) Crater Island granodiorite.

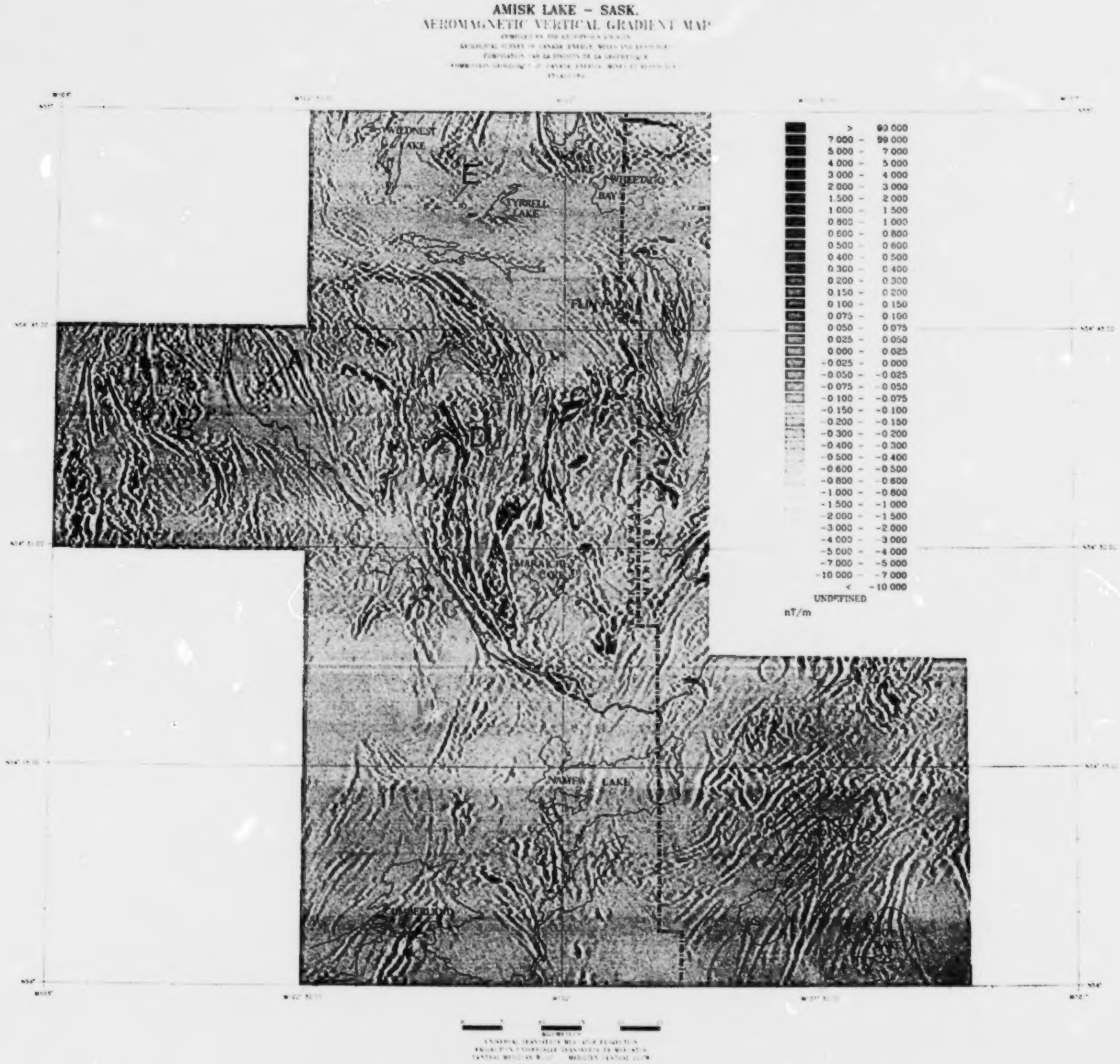
AMISK LAKE – SASK.
AEROMAGNETIC VERTICAL GRADIENT MAP
WILDNEST LAKE
E
TYRRELL LAKE
BAY
FLIN FLON
A
B
C
D
NAMEW LAKE
> 99 000
7 000 – 99 000
5 000 – 7 000
4 000 – 5 000
3 000 – 4 000
2 000 – 3 000
1 500 – 2 000
1 000 – 1 500
0 800 – 1 000
0 600 – 0 800
0 500 – 0 600
0 400 – 0 500
0 300 – 0 400
0 200 – 0 300
0 150 – 0 200
0 100 – 0 150
0 075 – 0 100
0 050 – 0 075
0 025 – 0 050
0 000 – 0 025
−0 025 – 0 000
−0 050 – −0 025
−0 075 – −0 050
−0 100 – −0 075
−0 150 – −0 100
−0 200 – −0 150
−0 300 – −0 200
−0 400 – −0 300
−0 500 – −0 400
−0 600 – −0 500
−0 800 – −0 600
−1 000 – −0 800
−1 500 – −1 000
−2 000 – −1 500
−3 000 – −2 000
−4 000 – −3 000
−5 000 – −4 000
−7 000 – −5 000
−10 000 – −7 000
< −10 000
UNDEFINED
nT/m

Figure 6. Amisk Lake, Saskatchewan - aeromagnetic vertical gradient composite grey tone map. Areas of interest (A,B,C,D, and E) described in text included for cross reference to Figure 5.

Further detailed interpretive work by Kornik and Dugal (1989) in the southern half of the survey area to define domains within the Precambrian basement under the Paleozoic cover rocks is in progress. An outline of the preliminary domain divisions is presented in Figure 6 south of the Paleozoic - Precambrian demarcation line.

Waddy Lake Area

The area is about 40 kilometres southwest of Southend, located at the southern extremity of Reindeer Lake. This survey focused on the northern part of the greenstones which are part of the Central Metavolcanic Belt of the La Ronge Domain. Recent interest in detailed geological mapping has developed and metallogenic studies by universities and federal/provincial agencies have accelerated as a result of new gold finds by the exploration industry in the metavolcanic and intrusive rocks in proximity to Byers Fault. This aeromagnetic geophysical survey provides additional data to assist in the detailed mapping of the geology by delineating faults and lithological boundaries based on their magnetic signatures.

A number of gold occurrences in the survey area are spatially related to the Byers Fault (Coombe,1986), which is a major structural break striking predominantly east-west. This fault is visible on both the aeromagnetic and vertical gradient maps. The fault trace is most clearly defined on the vertical gradient map where it shows up as a strong high-low magnetic signature. The Oven Lake-Corner Lake fault subsets (Harper,1984) paralleling the Byers Fault are equally well defined on the aeromagnetic maps and supported by VLF-EM responses along strike (Figure7). There are other examples of magnetic and VLF signatures throughout the metavolcanic sequence where east-west faulting is nearly parallel to the strike of the rocks, which are not easily recognized by conventional geological mapping. Numerous northeast striking fault sets in the Weedy Lake area and elsewhere throughout the survey area are also visible on the vertical gradient maps. Their fault trace is indicated by displacements or abrupt termination of the axes of east-west striking magnetic rocks.

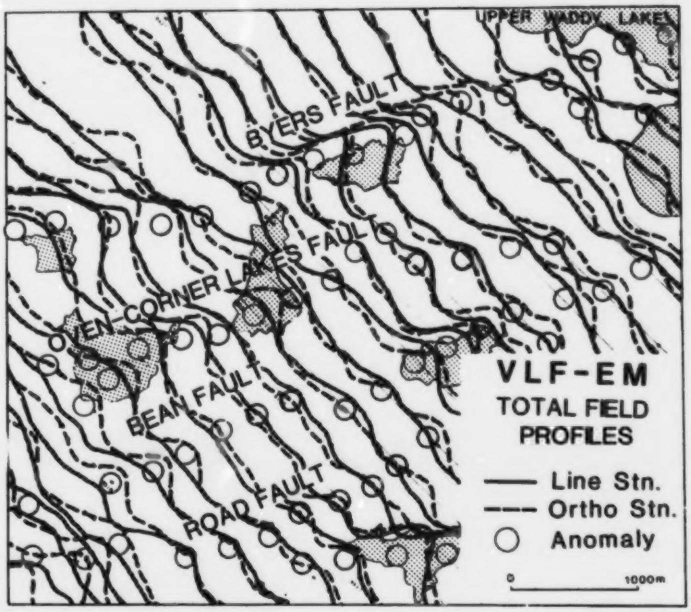

Figure 7. Waddy Lake, Saskatchewan - Total Field VLF-EM profile responses over Byers Fault and parallel subset faults reproduced from the reverse side of the aeromagnetic vertical gradient 1:50,000 scale maps.

CONCLUSION

The primary objectives of these airborne geophysical surveys to improve the accuracy of geological maps by complementing other geoscience mapping projects and to assist in outlining new areas of potential for mineral exploration has been realized in this geoscience MDA program.

These aeromagnetic maps have served as an effective and efficient tool in resolving structural and lithological features in great detail and have demonstrated their usefulness in defining lithology under surficial drift or deep below the cover of sedimentary rock. These products should also be a significant aid in base metal/gold exploration programs in the Precambrian Shield of Manitoba and Saskatchewan.

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SURFICIAL GEOLOGY AND DRIFT PROSPECTING, NORTHWESTERN MANITOBA

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INTRODUCTION

In glaciated regions, most primary surficial sediment has been formed by glacial erosion and transport of fresh bedrock, with secondary chemical processes restricted to development of a relatively weak post-glacial solum or soil. Till, the preferred sampling medium in drift prospecting programs, is considered to most closely reflect the composition of underlying bedrock, because it has undergone a relatively simple cycle of erosion and transport solely by glacier ice. Glaciofluvial sediment, on the other hand, has undergone an additional cycle of erosion and transport by meltwater, whereas glaciolacustrine sediment reflects the combined influence of glacial and glaciofluvial processes as well as redistribution within proglacial lakes. All modern or Holocene surficial materials derived from, or developed on, glacial sediment (i.e. modern lake sediment, stream sediment, peat) produce a geochemical signature that reflects, at least in part, the mineralogical composition of glacial sediments as well as underlying bedrock. For this reason, the success of surficial geochemical exploration in glaciated terrain (i.e. soil, peat, lake sediment, till, stream sediment etc.) depends upon a basic understanding of the glacial history of any given region, of the distribution, and physical and geochemical characteristics of various types of surficial materials, and of near-surface weathering processes.

Objectives

Prior to 1982, recognition and application of drift prospecting as an effective method of geochemical exploration in northern Manitoba was virtually non-existent. Preliminary drift prospecting studies were begun in the Lynn Lake region in 1982 (Nielsen, 1982), and in 1983, a program of systematic till sampling and surficial geologic mapping was begun in northwestern Manitoba, as part of the Federal - Provincial Mineral Development Agreement. The study area was centred on the Lynn Lake - Rusty Lake Greenstone Belt, extending northward to encompass the Southern Indian Gneiss Belt and southward across the Kisseynew Gneiss Belt (Figure 1). A primary objective in most regional till sampling is to identify the lithologic components of till that reflect various bedrock sources, and to map out the patterns of glacial dispersal developed through glacial erosion and transport of distinctive bedrock lithologies. These data, combined with detailed surficial geologic mapping can be used to aid in the design and implementation of prospecting programs aimed at locating sources of mineralized erratics and drift. The primary objective of this study was to provide reconnaissance-level till geochemical data in order to outline regions with potential for mineralization (primarily base metals and gold), identify areas for further detailed study, and provide the geologic framework for implementation of successful detailed drift prospecting programs within the region. In addition, information regarding the distribution and composition of surficial sediments, and surface weathering processes, provide baseline geological information for interpretation of regional geochemical surveys based on other surficial sampling media (ie. modern lake sediment), and assessment of the environmental impacts related to acid rain, smelter emissions, and mine waste treatment.

The Lynn Lake region was selected as the focus of these studies for several reasons:

1) The Lynn Lake greenstone belt has long been a focus for base metal and Au exploration and production in northern Manitoba. Development of sampling and analytical techniques for drift prospecting in the area would provide an effective new method of both regional and property-level exploration within the region.

2) Results of regional till geochemical surveys could outline regions with potential for mineralization and stimulate further exploration within the region, as well as provide a framework for interpretation of geochemical surveys based on other sampling media (ie. modern lake sediment)

3) Regional surficial geology and ice flow history was poorly known, limiting successful application of any drift prospecting programs likely to be carried out independently by industry.

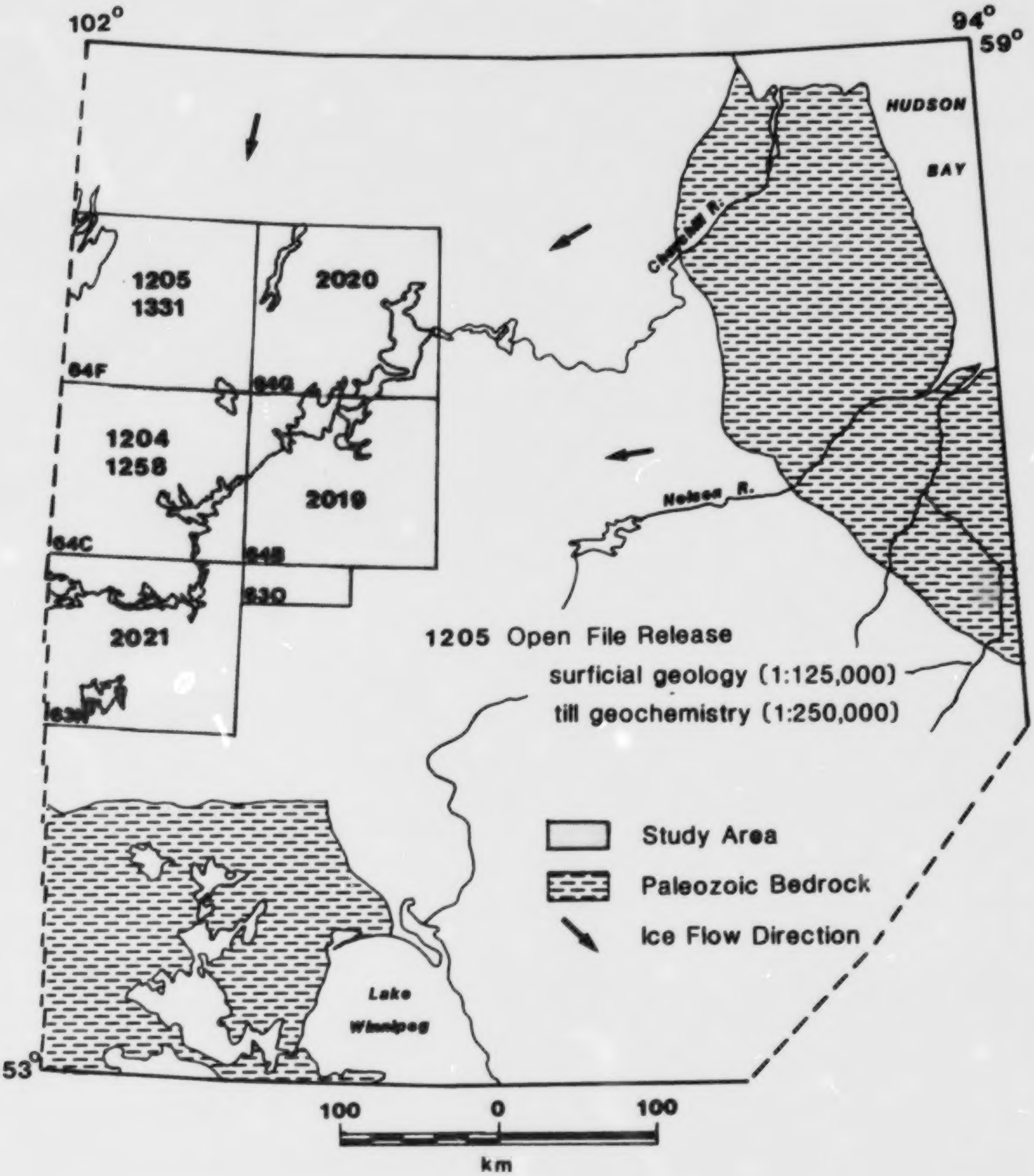
102°
94°
59°
53°
HUDSON
BAY
Churchill R.
Nelson R.
1205
1331
2020
1204
1258
2019
2021
64F
64G
64C
64B
63O
63N
1205 Open File Release
surficial geology (1:125,000)
till geochemistry (1:250,000)
Study Area
Paleozoic Bedrock
Ice Flow Direction
Lake
Winnipeg
100
0
100
km

Figure 1. Location of study area. Ice flow arrows represent major trends within the region.

Outputs

Regional till sampling and surficial mapping has been completed for five 1:250,000 map areas, including the Uhlman Lake (64B), Granville Lake (64C), Brochet (64F), Big Sand Lake (64G), and Kississing (63N) NTS map sheets. Till sampling was also carried out over parts of the Cormorant Lake (63K) and Nelson House (63O) NTS map areas. More detailed sampling was carried out in selected areas, as follow-up studies based on anomalies identified through regional till geochemical surveys (Suttner, 1989; Kaszycki, 1988; Kaszycki et al, 1988; DiLabio and Kaszycki, 1988). In addition, detailed profile sampling was carried out wherever exposure permitted, in an effort to evaluate in situ geochemical variability in response to both primary sedimentological factors and secondary surface weathering phenomena (Kaszycki, 1987). Two small till sampling projects were also carried out to address environmental issues, one assessing the impact of airborne pollutants from the smelter in Flin Flon on the geochemistry of surficial sediments (Samson, 1986), and one evaluating the sensitivity of surficial deposits within the region to acidification by acid rain (Samson, 1989).

Preliminary surficial geology maps at a scale of 1:125,000 have been released as GSC Open File Reports (Kaszycki et al., 1986, 1989; Kaszycki and Way Nee,.1989a, 1989b, 1989c) (Fig. 1). Till geochemistry data have been released as GSC Open File Reports, at a scale of 1:250,000 for NTS 64C and NTS 64F (Kaszycki and DiLabio,1986a; DiLabio and Kaszycki, 1986), and as a summary Open File Report combining till geochemical data for all map sheets at a scale of 1:1,000,000 (Kaszycki, 1989). A final summary publication, including five, 1:250,000 colour A-Series surficial geology maps (GSC Maps, 1757A, 1758A, 1759A, 1760A, 1761A, in press) is scheduled for early 1990.

In conjunction with regional till sampling, detailed sampling projects in the vicinity of known deposits were carried out by the Manitoba Department of Energy and Mines, in order to evaluate the geochemical signature of various types of mineralization within the region, and the scale and form of glacial dispersal related to individual deposits (Nielsen,1982, 1983, 1985, 1986a, 1986b, 1987a, 1987b; Nielsen and Fedikow, 1986, 1987; Nielsen and Gobert, 1988; Nielsen and Graham, 1984, 1985; Nielsen et al., 1985; Gobert and Nielsen, 1989).

In addition to till sampling, a subproject was designed to evaluate the influence of Lake Agassiz clay on the geochemistry of modern lake sediments. Regional sampling of Lake Agassiz clay was carried out in an effort to characterize the geochemical signature of allochthanous clays within the region and to identify relationships, if any, to modern lake sediment geochemistry and/or local bedrock. Reconnaissance geochemical data for till, modern lake sediment (GSC Open File 999, Hornbrook et al., 1984) and glaciolacustrine clay were compared to bedrock geology and evaluated in terms of their sensitivity to lithologic variation (Kaszycki and DiLabio, 1986b). Detailed profile sampling of Lake Agassiz varves was undertaken to evaluate in situ geochemical variability related specifically to summer versus winter sedimentation (Suttner. 1986). Selected lake basins were studied in detail, using sonar and coring techniques, to evaluate the influence of the types of surficial sediment within and surrounding lakes, on the geochemistry of modern lake sediment. Continuous sediment cores were analyzed in order to define vertical geochemical variations, and to identify relationships between hydrologic pathways and hydromorphic dispersion of trace elements in modern lake sediments. A final report summarizing the influence of Lake Agassiz clay on the geochemistry of modern lake sediment is scheduled for publication in early 1990.

METHODOLOGY

Helicopter-supported sampling was carried out at a density of approximately 2-3 samples per 100 km2 (average sample spacing 7 - 8 km). Sampling density was increased in areas of road access and restricted in areas of extensive clay cover. Shallow surface samples from approximately 1 m depth were collected from hand-dug pits. In the eastern part of the study area, till is commonly covered by a veneer of Lake Agassiz clay. In some areas, particularly near eskers and moraines, glaciolacustrine deposits may achieve thicknesses in excess of 50 m. Throughout most of the region however, clay is present as a relatively thin veneer, draping topographic highs and filling topographic lows. In these areas, at elevations >1000 ft (~ 300 m) till can usually be sampled near the summits of small hills or knolls beneath 50 to 100 cm of clay.

Initially, relatively small (2.5 kg) samples were collected, in order to maximize the number of samples obtained per helicopter payload. However, as sampling became more difficult and time consuming due to increased clay cover, sample size was increased to 5 kg, enabling a broader range of analytical techniques to be used. Care was taken to sample below the post-glacial solum, and almost all samples are classified as oxidized C horizon material (parent material). In general, labile minerals such as sulphides have been weathered from these samples, and in some instances carbonate has been leached.

Till samples were routinely subjected to a number of analytical techniques. In reconnaissance level till sampling programs where sample spacing ranges up to 10 km, a large background to anomaly ratio is required in order to resolve geochemical patterns and identify mineralized debris that may have been dispersed and diluted over distances varying from 100's of metres to several kilometres. The clay-sized (<2µm) fraction of all samples was analyzed for trace element composition related to base metal sulphide mineralization because:

1) concentrations of many trace elements are greater in this fraction than in coarser size fractions due to primary enrichment of metal in the structure of phyllosilicates, which dominate this size fraction (Shilts, 1984);

2) it provides a more uniform sampling medium than sample subsplits comprising a wider range in grain size (e.g. minus 80 mesh, which commonly contains variable amounts silt and sand dominated by inert quartz and feldspar), thereby minimizing geochemical trends related to grain size variation in the till (Shilts, 1975).

3) it is known to reflect sulphide mineralization because it will adsorb a representative portion of trace elements released during the weathering of labile minerals (Shilts, 1975, 1984).

Clay separated by centrifugation and decantation was analyzed by Bondar-Clegg Co. Ltd. (in 1983, 1984, 1985, 1986) and by Chemex Labs (in 1987, 1988) for Cu, Pb, Zn, Ni, Cr, Mn, Fe, Mo, Cd, Co, and Ag, using standard atomic absorption techniques after a hot acid (HNO3-HCl) leach. Arsenic was analyzed using colourimetric techniques and uranium was determined by fluorimetry (in 1983, 1984) and by neutron activation/delayed neutron counting (in 1985, 1986, 1987, 1988).For a complete listing of sample location, description and geochemistry refer to Kaszycki (1989).

In addition, the silt plus clay (<63 µm or <230 mesh) fraction of most tills was analyzed for Au by direct irradiation neutron activation in a Au plus 33 element package. This size fraction was chosen because of the large sample size required for analysis (>10 g) as well as the fact that gold in this region most commonly occurs as silt-sized particles, both in bedrock and derived tills (Sopuck et al., 1985; DiLabio, 1985; Brereton et al., 1988). This size fraction was also analyzed for carbonate content using a Leco induction furnace.

Heavy mineral separates were concentrated from selected samples by Overburden Drilling Management Ltd., Ottawa, and grain counts for visible gold were carried out. Heavy separates were then analyzed for Au by fire assay with an atomic absorption finish. In addition, lithological identification of the pebble fraction (2-6 mm) of selected samples was carried out in order to identify regional ice flow indicators as well as potential source rocks for mineralization observed geochemically within other till fractions.

Beginning in 1985, analytical quality control was monitored by insertion of 10% standards and blind duplicates within each sample batch. Subsets of samples analyzed prior to 1985. were reanalyzed in order to establish reproducibility. In most cases analytical variability fell within the tolerance limits set by analytical laboratories for various techniques. When analytical variability exceeded tolerance limits, samples were resubmitted and re-analyzed.

SURFICIAL GEOLOGY

Throughout the extreme western part of Manitoba, Late Wisconsinan ice flow was from a Keewatin ice centre to the north, and till in this region is derived predominantly from crystalline shield lithologies (Figure 1). Farther east, ice flow originated from a centre of outflow in Labrador and till in this area contains abundant Paleozoic carbonate erratics derived from Hudson Bay and adjacent lowlands.

Morphological evidence and till composition suggest that during deglaciation the zone of convergence between Keewatin ice and Labradorean ice was located in the Leaf Rapids area (Kaszycki and DiLabio, 1986c) . This zone is marked by a discontinuous north-south trending ridge composed of ice contact stratified sediment, termed the Leaf Rapids Interlobate Moraine (LRIM) (Figure 2). East of the LRIM, striae record a clockwise rotation of Late Wisconsinan ice flow from approximately 190√ - 210√ (main Late Wisconsinan) to 260√ (youngest) and till contains abundant Paleozoic carbonate, and Proterozoic greywacke of Hudson Bay and eastern provenance. To the west, striae record a counterclockwise shift in ice flow from 190√ - 210√ (main Late Wisconsinan) to 165√ (youngest) and till is dominated by crystalline shield lithologies. Eskers within the study area also exhibit a convergent pattern in the vicinity of the Leaf Rapids interlobate moraine.

The LRIM extends southward as far as the eastern extension of the Cree Lake Moraine (Fig. 2). The Cree Lake Moraine extends westward through Saskatchewan and into the Northwest Territories and marks a major ice marginal position during retreat of Keewatin ice (Schreiner, 1984; Schreiner and Alley, 1984). South of the Cree Lake Moraine, there is no evidence for a zone of convergent ice flow during deglaciation, and it is assumed that the zone of convergence between Keewatin and Labradorean ice did

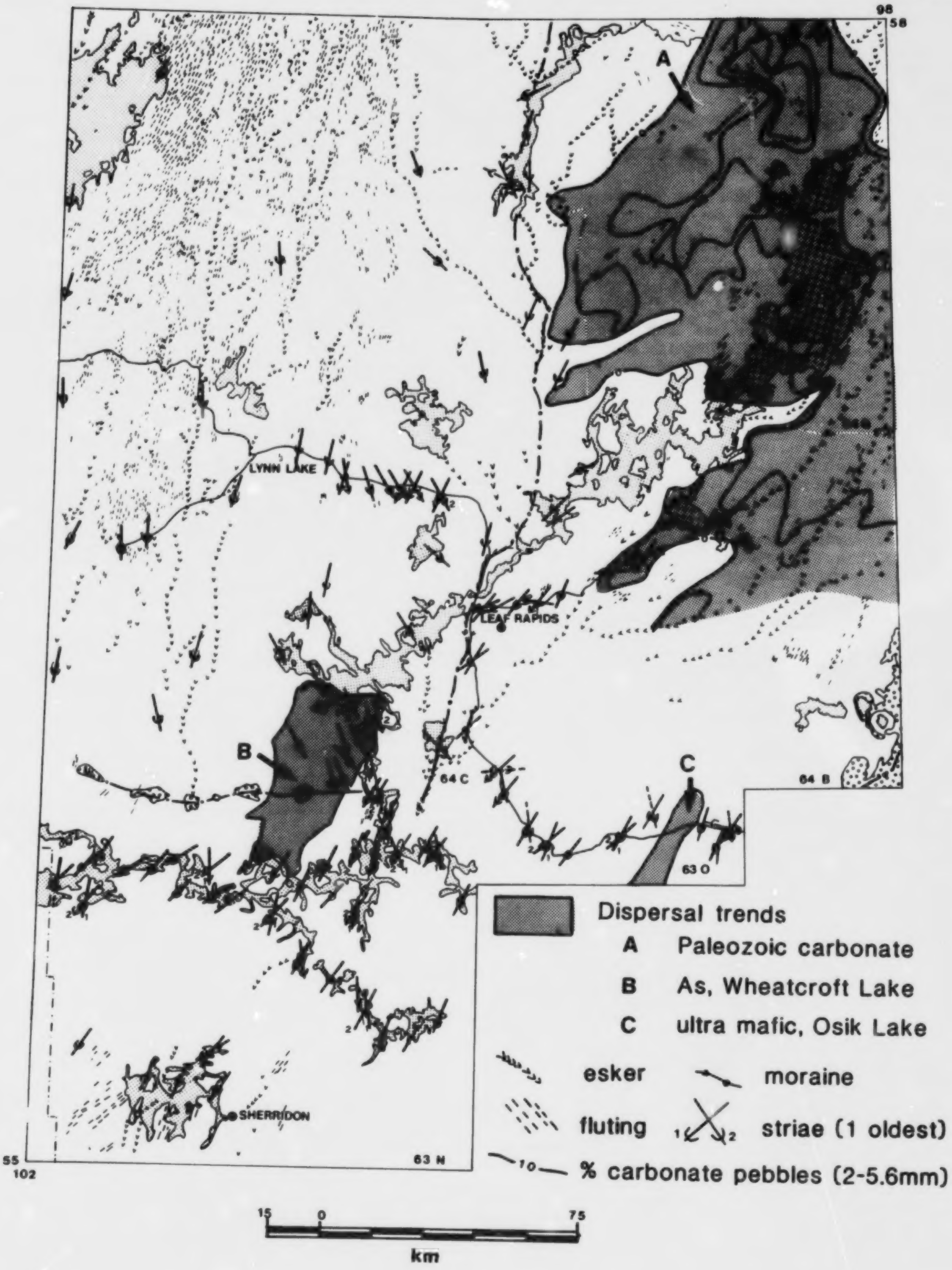
98
58
A
LYNN LAKE
LEAF RAPIDS
B
64 C
C
64 B
63 O
SHERRIDON
55
102
63 N
Dispersal trends
A Paleozoic carbonate
B As, Wheatcroft Lake
C ultra mafic, Osik Lake
esker
moraine
fluting
striae (1 oldest)
% carbonate pebbles (2-5.6mm)
15
0
75
km

Figure 2. Glacial landforms and major dispersal patterns.within the study area.

not develop until the ice margin had retreated to this position. Dispersal patterns and ice flow indicators south of the Cree Lake moraine suggest that the deglacial zone of convergence between Keewatin and Labradorean ice in the Leaf Rapids area was preceded by a more extensive main Late Wisconsinan zone of parallel and confluent ice flow between these two ice masses.

Regional Ice Flow History

Several ice flow events have been documented based on the striation record within the region (Figure 2). The oldest striae trend approximately due west and have been observed at only two sites. Extrapolation of this flow event is tenuous, however it is possible that these striae correlate with those observed in the Lac La Ronge area of Saskatchewan (Johnston,1978; Schreiner, 1984), and may reflect a pre-Main Late Wisconsinan advance of Labradorean ice across the Prairies postulated by Prest and Nielsen (1987) and Prest (in press) to account for the distribution of distinctive greywacke erratics derived from eastern Hudson Bay.

A second set of old striae trend to the southeast, with orientations ranging from 175√ to 140√ (observed at ~30 sites). Cross-cutting relationships have not been observed between these and westerly trending striae. In this case relative age has been based on frequency of observation (southeasterly trending striae are more common, approximately 30 obvservations). These striae are distributed throughout the study area suggesting that prior to the latest ice flow event the entire region was occupied by ice of Keewatin provenance.

Southeasterly striae are crosscut by southwesterly trending striations ranging from 190√ to 210√. At some sites the range in striae orientation suggests that the shift from southeasterly to southwesterly ice flow was transitional and was not interrupted by a nonglacial event. This southwesterly ice flow direction is regionally pervasive and is interpreted as the main Late Wisconsinan ice flow event. The youngest striae in the region record late glacial shifts in ice flow related to style of deglaciation and ice marginal configuration. South of the Cree Lake Moraine (Fig. 2) the youngest striae record a westward shift in ice flow. North of the Cree Lake Moraine, the youngest ice flow indicators record a late glacial zone of convergent ice flow marked by southeasterly striae west of the Leaf Rapids interlobate moraine and southwesterly striae to westerly striae east of the moraine (Fig.2).

Till Composition and Provenance

Lateral variations in regional till provenance significantly influence texture, mineralogical composition and geochemistry of tills throughout the study area. In the east, surface till is silty and calcareous, whereas to the west, surface till is sandy and noncalcareous. The change from silty calcareous till to sandy noncalcareous till is gradual and till in the central transitional zone may be sandy to silty and slightly calcareous to carbonate-free. Carbonate concentration in till increases systematically toward the northeast, achieving concentrations in excess of 60% in the granule fraction and 35% in the silt plus clay size fraction (Figure2). The 0% carbonate contour does not represent the western limit of carbonate dispersal, but rather marks a zone of lower concentration and surface weathering and leaching. West of this contour, clay cover is thin and discontinuous and leaching of carbonate is prominent. Samples containing carbonate are found sporadically throughout this region and carbonate in low concentration (1 - 2%) can be traced in deep roadcuts up to 30 km west of the Leaf Rapids interlobate moraine. The depth of leaching varies from 1 to 2 metres. The transition from leached to unleached till is not marked by visible colour or textural changes; in shallow surface samples these leached carbonate-poor tills are visually indistinguishable from shield tills of Keewatin provenance.

Stratigraphy

The stratigraphic succession observed within the study area is, in general, related to late glacial and deglacial events. It is possible that older units are preserved as isolated pockets within bedrock troughs (W. E. Brereton, pers. comm., 1989), however, it is impossible to document this stratigraphy without the aid of a stratigraphic drilling program. In general, only one till unit is present as a relatively thin veneer on bedrock. Thick till sequences commonly occur on the down-ice side of bedrock knobs. Detailed profile sampling below the post-glacial solum did not reveal any systematic geochemical variations in till composition with depth.

A multiple-till stratigraphy has been observed in river sections in the northeastern part of the study area. The absence of fossil organic materials and weathering horizons argues against deposition over a prolonged time interval and this stratigraphy has been interpreted to represent minor readvances or surges of both Keewatin and Labradorean ice masses during deglaciation.

Glacial Dispersal

Glacial dispersal can be mapped at scales that vary from regional (100's km) to local (1-10's km) to detailed (<1km) (Shilts, 1984). In this study, reconnaissance till sampling (average spacing 7 - 8 km) enabled definition of dispersal trains at both the regional and local scales.

Regional Dispersal

In the Lynn Lake - Leaf Rapids region, the distribution of Paleozoic carbonate marks the end of a regional dispersal train extending from Hudson Bay, approximately 300 km across the Canadian Shield (Figure 2). Dispersal trends in highly calcareous till are oriented approximately 230°, parallel to late glacial ice flow indicators, suggesting that in the northeastern part of the study area, most carbonate was transported into the area during deglaciation and disintegration of the ice sheet. However, carbonate is also present in small quantities (<5%) within a local ultramafic dispersal train trending 210° (Figure 2), suggesting that carbonate, in low concentrations, was also being transported into the region during the main Late Wisconsinan ice flow event.

Exotic debris may hinder interpretation of regional till geochemistry by influencing background concentrations and the resolution of local geochemical anomalies. In some instances, far-travelled debris may be geochemically impoverished with respect to local bedrock, the net result being a 'negative' dispersal train and a geochemical suppression of local mineralization (Klassen and Shilts, 1977; Shilts, 1984). Alternatively, geochemically distinctive debris may be dispersed over a large area metal-poor bedrock lithologies, leading to an incorrect assessment of mineral potential for the region.

Local Dispersal

It is this scale that is most significant in reconnaissance till sampling, as the detection of the tails of these trains provides an indication of local mineralization within the region. In the Lynn Lake - Leaf Rapids region, the dominant dispersal direction is to the southwest at approximately 200° - 210°, parallel to the main Late Wisconsinan ice flow direction. At Wheatcroft Lake (Figure 2), a train of As-enriched till extends from a zone of sulphide mineralization south of Granville Lake, southwestward over a distance of at least 60 km (Kaszycki et al., 1988). Within the northern part of this train (closest to source) the dominant striae orientation is southeastward, parallel to a late glacial shift in ice flow. This southeastward ice flow however, has had no observable affect on glacial dispersal at this scale. In instances such as this, where the local striation record is dominated by relatively short-lived deglacial events that may not have significantly influenced glacial dispersal, it is necessary to have a knowledge of regional ice flow history, in order to effectively evaluate potential sources for mineralized debris.

Detailed Dispersal

Detailed studies of till geochemistry and glacial dispersal with the Lynn Lake - Leaf Rapids area have been carried out by Erik Nielsen, Manitoba Department of Energy and Mines (Nielsen, 1987b; Nielsen and Fedikow, 1986, 1987; Nielsen and Graham, 1985). Because sulphide mineralization within the study area generally occurs as relatively thin stratiform deposits (Baldwin, 1980) with small areas of surface exposure, the size of source area for glacial erosion and dispersal is relatively small. This, coupled with irregular bedrock topography and resistant bedrock lithologies results in dispersal trains that are short and/or poorly developed. Results of detailed studies indicate that down-ice transport of material derived from areas of known mineralization cannot be traced farther than 1 - 2 km. Because transport distance is short, dispersal trends at this scale may reflect late glacial shifts and/or topographic deflection of ice flow, rather than main Late Wisconsinan ice flow trends. The sampling density employed in reconnaissance programs is unlikely to result in the intersection of these small dispersal trains. Geochemical trends and dispersal patterns identified in regional surveys likely reflect metal-enriched bedrock units with potential for hosting small volcanogenic sulphide bodies, rather than the small sulphide bodies themselves.

TILL GEOCHEMISTRY

Two main factors influence the geochemical signature of surface till in any region: 1) lithic composition, specifically the proportion of local to far-travelled debris; and 2) the surface weathering environment. The effects of surface weathering can be minimized by sampling till below the postglacial solum. If appropriate sampling control is exercised, trace element composition in till should reflect, to a first approximation, variations in lithic composition. In this discussion, regional till geochemistry refers to background variations in trace element concentration related to either the lithologic composition of till and/or surface weathering conditions. The discussion of local till geochemistry focusses on subregions defined by anomalous trace element concentrations, in an attempt to identify mineralized zones, and the lithologic setting for mineralization within under-explored parts of the region.

Bedrock Geology and Mineralization

Bedrock lithologies within the region can be grouped into four major domains: metasediments and gneisses of the Kisseynew Sedimentary Gneiss Belt and the Southern Indian Gneiss Belt; metasediments and metavolcanics of the Lynn Lake

- Rusty Lake Greenstone Belt; and granitic intrusives of the Chipewyan Batholith (Figure 3). Lithologies in all domains, with the exception of the Chipewyan Batholith, are intruded by felsic to mafic plutonic bodies classified as younger plutonic rocks (post-Sickle intrusives), plutonic rocks of indeterminate age, and older plutonic rocks (pre-Sickle intrusives).

The Kisseynew Gneiss Belt is flanked to the north and south by the Lynn Lake - Rusty Lake Greenstone Belt and Flin Flon - Snow Lake Greenstone Belt respectively. The centre of the Kisseynew belt is composed of greywacke and derived gneisses and migmatites of the Burntwood River Metamorphic Suite (BRMS) (unit 2). The northern and southern flanks of the belt consists of by quartzofeldspathic gneisses and migmatites derived from arkose, sandstone, conglomerate termed the Sickle Group and Missi Metamorphic Suite respectively (unit 3). The Sickle Group conformably overlies the BRMS along the northern margin of the belt, the contact marked by interbedded metavolcanics (amphibolites) and metasediments. Mineralization is conformable, stratiform and widespread, occurring as disseminated and massive iron sulphide, with minor chalcopyrite, arsenopyrite and sphalerite at or close to the Sickle Group - BRMS contact The zone most favourable for mineralization is that containing amphibolite at the top of the BRMS and meta-arkosic rocks in the lower part of the Sickle Group (Baldwin, 1980). At the southern margin of the basin, it has been postulated that known Au mineralization occupies a stratigraphic position similar to that of known massive sulphide occurrences associated with a thin unit of volcanogenic and sedimentary rocks that occur at the contact between the BRMS and Missi Metamorphic Suite (Gale and Ostry, 1984).

The Lynn Lake - Rusty Lake Greenstone Belt marks the northern margin of the Kisseynew Gneiss Belt. It is composed of metamorphosed volcanic, and volcaniclastic sedimentary rocks of the Wasekwan Group (unit 1), which have been intruded by mafic to felsic plutons (units 4a and 4b respectively) (Gilbert et al., 1980). Wasekwan Group rocks are unconformably overlain by sandstone and conglomerate of the Sickle Group, and are thought to be stratigraphically equivalent to at least the upper part of the BRMS. Mineralization within the Lynn Lake - Rusty Lake Greenstone Belt is widespread. At several localities Cu-Zn sulphide mineralization is hosted by Wasekwan Group metasediments and metavolcanics, and Cu-Ni mineralization is associated with gabbro intrusions (Gilbert et al., 1980). Stratabound disseminated to solid sulphide mineralization in felsic fine grained sediments and volcanic fragmental rocks is a particularly prevalent style of mineralization (Ferriera and Baldwin, 1984). Within the northern part of the belt, Au mineralization is stratabound, associated with thinly interbedded siltstone, iron formation and ultramafic komatiites within the Agassiz Metallotect (Fedikow, 1986). In the southern part of the belt, most Au deposits are structurally controlled, developed within quartz veins in metavolcanic or felsic intrusive rocks associated with the Johnson Shear Zone (Richardson and Ostry, 1986; Fedikow et al., 1986).

The Southern Indian Gneiss Belt is lithologically similar to the Kisseynew Gneiss Belt and was derived from an equivalent stratigraphic succession comprising greywacke, thin volcanic and mafic metasediments, overlain by arkosic rocks. However, metavolcanic units are localized and have been observed only in the Reindeer lake area (Schledewitz, 1983; McRitchie,1977; Schledewitz and Cameron, 1982). Mineral occurrences are rare but generally occur as massive and disseminated sulphides within metagreywacke and volcanogenic sediments (Gale et al., 1980)

Intrusive rocks of the Chipewyan Batholith flank the Southern Indian Gneiss Belt to the north and form the youngest rocks in the area. This domain is composed of a large volume of granitic intrusive lithologies, primarily a pink megacrystic granite (unit 4b). No known sulphide mineralization has been documented within this area.

Regional Till Geochemistry

Two major factors influence regional till geochemistry within the area: 1) till provenance, more specifically carbonate content; and 2) regional bedrock lithologic trends. In general, simple statistical techniques treating the entire data set as one sample population are inadequate to identify variations in background related to till provenance and/or changes in bedrock lithology. In order to more fully evaluate these relationships, the total sample population was subdivided on the basis of bedrock type and till provenance. Subpopulation means and 95th percentile values for each rock type and provenance group were then compared to values for the total population and significant differences in both background (mean) and anomalous (95th percentile) concentrations were identified.

Till Provenance

The most significant aspect of regional till composition within the study area is the lateral variation from sandy, non-calcareous till in the western part of the region, to silty, calcareous till in the east. In northwestern Manitoba, Paleozoic carbonate has been dispersed approximately 300 km across the Canadian Shield. In general, calcareous till (>5% $CaCO3$) is enriched in Co, Mn, and Zn and depleted in Cr, Au, and U compared to the total population (Figure 4).

Till provenance influences regional geochemistry in two ways: 1) glacial dispersal of large amounts of Paleozoic debris dilutes the debris contribution from local sources and background values may be either enhanced or diminished depending upon the concentration of various trace elements in exotic debris relative to local bedrock; and 2) the near surface weathering environment is significantly influenced by carbonate content and soil water pH, resulting in regional variations in trace element mobility. In areas dominated by calcareous till, soil water pH is alkaline (pH 7.5 - 8.5) reducing the mobility of many trace elements (Samson, 1989). In shield till, soil water pH is acidic (pH 5.5 - 4.5) resulting in increased mobility for most trace elements and lower background concentrations in near surface samples (Samson, 1989). The influence of till provenance on regional till geochemistry is illustrated by the distribution of Zn

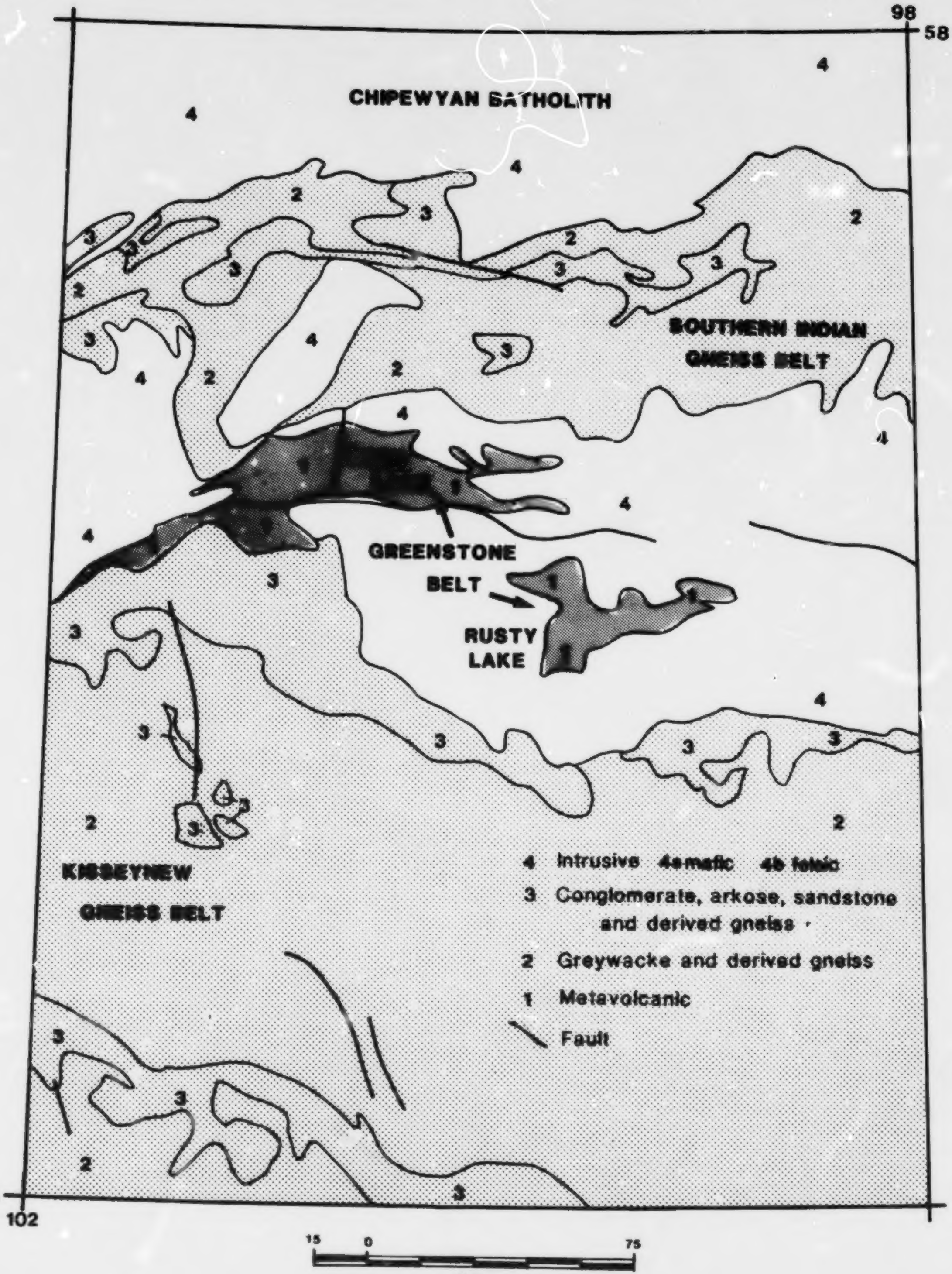
98
58
CHIPEWYAN BATHOLITH
SOUTHERN INDIAN GNEISS BELT
GREENSTONE BELT
RUSTY LAKE
KISSEYNEW GNEISS BELT
4 Intrusive 4a mafic 4b felsic
3 Conglomerate, arkose, sandstone and derived gneiss
2 Greywacke and derived gneiss
1 Metavolcanic
Fault
55
102
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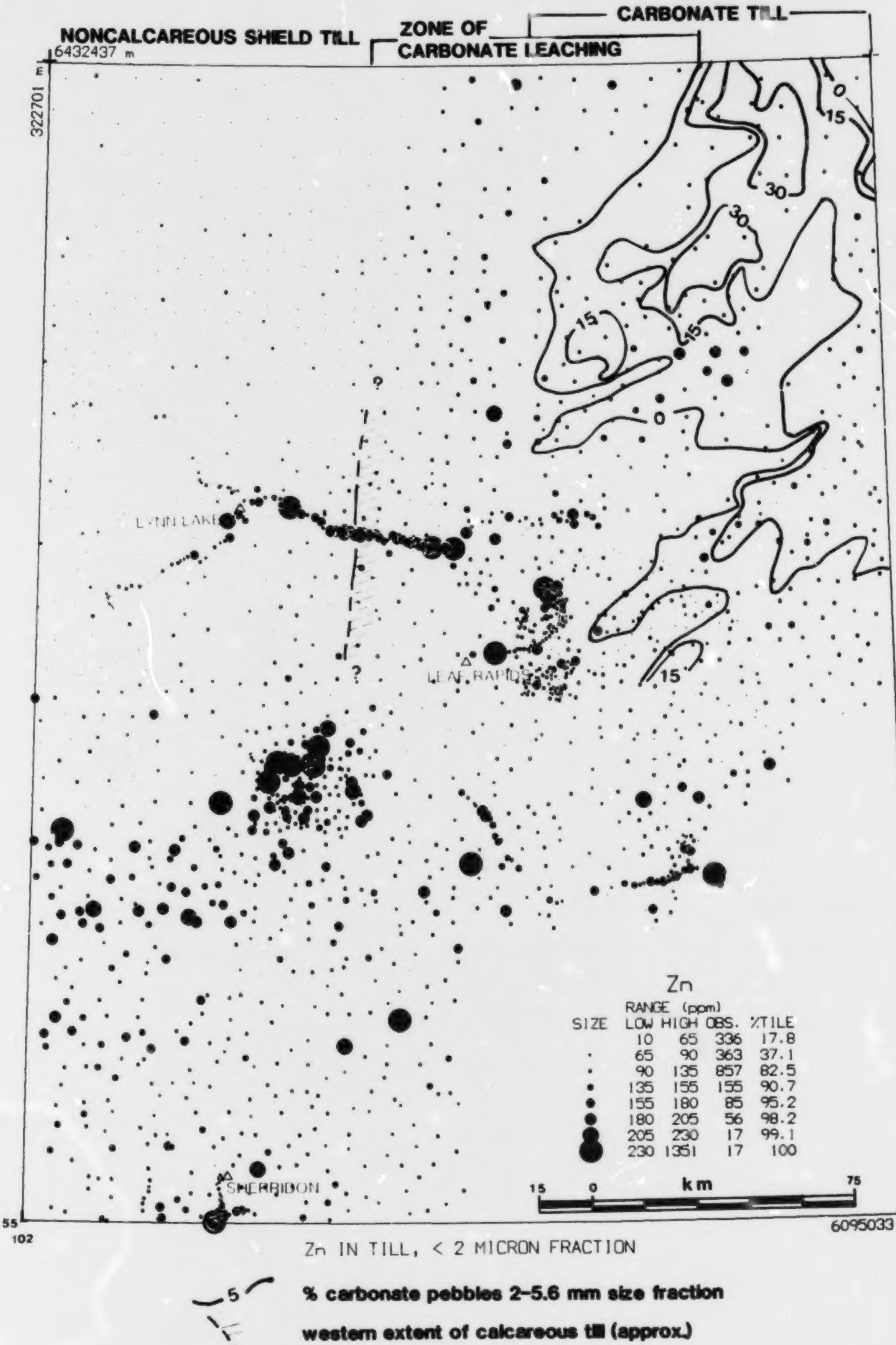
Figure 3. Lithologic domains within the Lynn Lake - Leaf Rapids - Sherridon areas. Units 4a and 4b are not differentiated on this map. Refer to Figures 6, 7 and 8.


NONCALCAREOUS SHIELD TILL
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LYNN LAKE
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Zn
RANGE (ppm)
SIZE LOW HIGH OBS. %TILE
10 65 336 17.8
65 90 363 37.1
90 135 857 82.5
135 155 155 90.7
155 180 85 95.2
180 205 56 98.2
205 230 17 99.1
230 1351 17 100
15 0 km 75
Zn IN TILL, < 2 MICRON FRACTION
5
% carbonate pebbles 2–5.6 mm size fraction
western extent of calcareous till (approx.)

Figure 4. Regional distribution of Zn in till, in relation to till provenance. Western extent of calcareous till based on observations from roadcuts.

in the clay fraction of till (Figure 4). In addition to alkaline surface environment, higher Mn and Zn concentrations observed in calcareous tills, may also reflect primary mineralogical enrichment related to glacial dispersal, possibly siderite-rhodochrosite and/or sulphide derived from Paleozoic lithologies. Zn concentration is also elevated in the southwestern part of the study area, reflecting lithologically controlled trends related to the distribution of greywacke and gneiss of the Kisseynew Gneiss Belt. The fact that calcareous tills are are depleted in Cr, Au, and U suggests that Paleozoic debris may significantly mask the geochemical signature of local bedrock lithologies for certain trace elements.

Bedrock Lithology

Bedrock lithologies were grouped into five categories: intrusives (predominantly felsic), extrusives (predominantly mafic), metagreywacke, terrestrial metasediments, and gneiss. The gneiss category is dominated by lithologies described as paragneiss and biotite gneiss of sedimentary origin.. This group therefore, likely represents high grade metamorphic equivalents of both metagreywacke and terrestrial metasediments. Arithmetic means and 95th percentile concentrations of trace elements in till on each bedrock group were compared to corresponding values for the total population (Table 1). In general, till derived from intrusive lithologies (granitic) is geochemically inert, producing the lowest background values for most base metals and Au. Elevated background concentrations for Co, Ni, and Cr found in till derived from metagreywacke and gneiss reflects a mafic sediment source, likely the Flin Flon - Snow Lake and Lynn Lake - Rusty Lake greenstone belts. The enrichment of Cu and Zn within the greywacke group may reflect the increased potential for disseminated and massive sulphide within this rock type (Baldwin, 1980). Elevated As concentration in till sampled over gneiss may be related, in part, to glacial dispersal rather than primary enrichment within this lithology (see Fig.6).

Geochemical patterns related to regional lithologic trends are well illustrated by Cr (Figure 5). Background concentration is elevated in the southwestern part of the study area underlain by gneiss and greywacke of the Kisseynew Gneiss Belt. This geochemical enrichment however, is not observed for similar lithologies forming the Southern Indian Gneiss Belt. Similar trends are also observed for Ni, Cu Zn and to a lesser extent Au.

Local Geochemical Trends

At a local scale (several to 10's of km), zones of anomalously high trace element concentration reflect potentially mineralized areas within regional bedrock lithologies. These patterns may be elongated in a direction parallel to ice flow, reflecting glacial erosion and transport of mineralized debris. In these cases the areal distribution of geochemically enriched debris may far exceed that of potentially mineralized source rocks. More commonly however, local scale anomalies exhibit irregular patterns closely reflecting the outcrop area of geochemically enriched source rocks.

Lithologic and provenance controlled trends in background concentration significantly influence the resolution of geochemical anomalies on a regional scale. Anomalous concentrations (>95th percentile) for some trace elements vary significantly between lithologic groups and in relation to the total population (Table 1). In particular, 95th percentile values for As, Au, Cu and Co are much higher in till derived from terrestrial metasediment than corresponding values for other lithic groups or the total population. Because the computer mapping techniques employed in this report treat the entire data set as one sample population rather than several, anomalies based on 95th percentile concentration may be over-represented within lithic groups characterized by elevated background concentrations and under-represented in those with low background concentration. It is important to interpret geochemical anomalies or local bedrock trends with these variations in mind.

Glacial Dispersal

Arsenic is the only element for which well developed dispersal trains can be mapped. Figure 6. illustrates four well developed As dispersal trains and one zone of elevated As concentration. Three of the four dispersal trains exhibit well defined head and tail relationships, trending approximately 200√-210√, parallel to the Main Late Wisconsinan ice flow direction, and relatively uninfluenced by late glacial shifts in ice flow. In general, up-ice end of all zones of elevated As concentration correlate with the contact between terrestrial metasediments (unit 3) and underlying metagreywackes (unit 2) and/or metavolcanics (units 1). These trains can be traced for distances varying from 50 to 100 km. The large distances over which As-enriched till has been transported down-ice from source reflects either, a large single source, significantly enriched in arsenopyrite, or the cumulative effect of glacial dispersal from a number of small sources within the train. In either case, it is significant that As-enrichment occurs only at specific sites along the contact between units 2 and 3, suggesting unusual mineralogical conditions within these areas. The most common site of deposition of disseminated sulphide along this contact is in the amphibolites marking a transition zone from the metagreywackes of the BRMS (unit 2) and overlying Sickle Group lithologies (unit 3), and in interlayered graphitic metagreywackes and amphibolites at the top of the BRMS (Baldwin, 1980). Arsenopyrite may be associated with stratiform syngenetic Cu mineralization at the base of the Sickle Group related to changes in redox conditions at the contact, organic complexing and the increase in graphite bearing metagreywacke near the stratigraphic top of the BRMS , and/or tectonism at stratigraphic contacts often associated with Au mineralization.

At Wheatcroft Lake (zone 1, Figure 6), a zone of known Cu sulphide mineralization coincides with the head of the dispersal train (Baldwin, 1980). No other sulphide occurrences have been documented south of this belt, suggesting dispersal results from erosion and transport from a single large source near the head of the train. The source likely

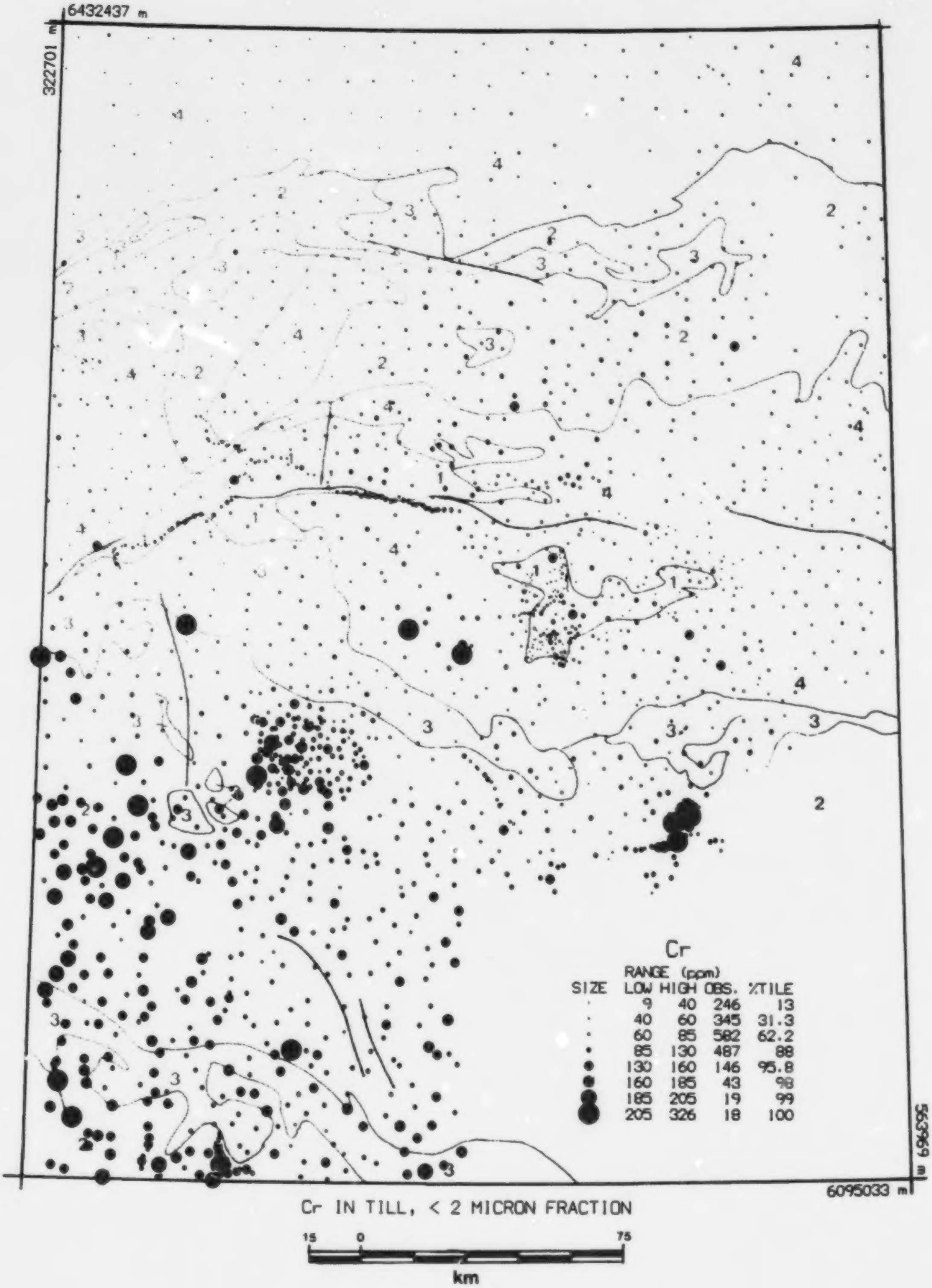
6432437 m
322701 m
563969 m
6095033 m
1
2
3
4
Cr
RANGE (ppm)
SIZE LOW HIGH OBS. %TILE
9 40 246 13
40 60 345 31.3
60 85 582 62.2
85 130 487 88
130 160 146 95.8
160 185 43 98
185 205 19 99
205 326 18 100
Cr IN TILL, < 2 MICRON FRACTION
15 0 75
km

Figure 5. Regional distribution of Cr in till, in relation to lithologic trends. Refer to Figure 3 for explanation of bedrock units.

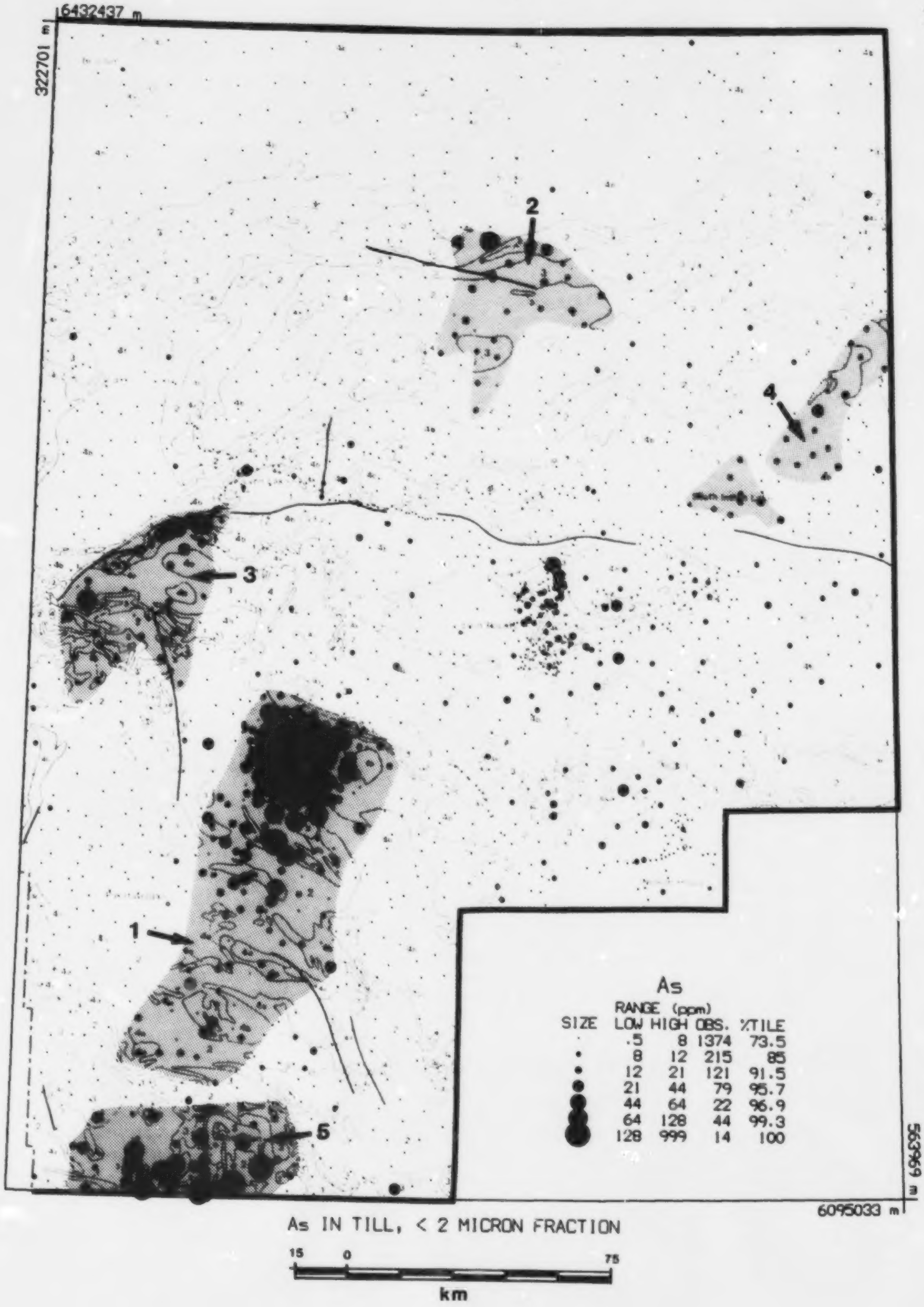
6432437 m
322701 m
2
4
3
1
5
As
RANGE (ppm)
SIZE LOW HIGH OBS. %TILE
.5 8 1374 73.5
8 12 215 85
12 21 121 91.5
21 44 79 95.7
44 64 22 96.9
64 128 44 99.3
128 999 14 100
563969 m
6095033 m
As IN TILL, < 2 MICRON FRACTION
15
0
75
km

Figure 6. Regional distribution of As in till, in relation to bedrock geology. Shaded areas represent regional anomalies and major dispersal trains. Bedrock geology from Manitoba Mineral Resources Division, Map 79-2. Refer to Figure 3. for explanation of bedrock units.

represents a broad zone of widely disseminated arsenopyrite at the contact between metasediments of the Sickle Group (unit 3) and metagreywackes of the BRMS (unit 2). Several samples from this region are also anomalous with respect to Cu, Zn, U and Au. Although none of these elements exhibits a pattern related to glacial dispersal, the assemblage of anomalies may suggest that As mineralization may be, in part, related to Cu mineralization in meta-arkose and metaconglomerate of the Sickle Group. However, Au anomalies in this area appear to be more closely associated with felsic intrusives than sulphide occurrences (Kaszycki et al., 1988).

Similarly, the Le Clair Lake dispersal train (zone 2), appears to be derived from a single large source located at or near the contact between terrestrial metasediments (unit 3) and metagreywacke (unit 2) within the Southern Indian Gneiss Belt. No other trace element anomalies are associated with As dispersal in this area. The head of this dispersal train lies up-ice (ie. north and east) of the only known sulphide mineralization in the region. Disseminated sulphides occur within a shear zone along the northern margin of Le Clair Lake (Schledewitz, 1983), but have not been documented elsewhere. Detailed till sampling has been carried out in the vicinity of the shear zone at Le Clair Lake (Nielsen, 1985) however, results have not been published.

The Wilmot - Gemmell Lake dispersal train (zone 3), may reflect, in part, the occurrence of numerous small sulphide sources known to occur within the dispersal area. As and Cu mineralization has been documented at several sites within this area, and the head of the train outlines a zone of arsenopyrite-bearing mafic tuff and quartzite, associated with known Au mineralization (Richardson and Ostry, 1987). Till within parts of this As dispersal train is also enriched in Cu , but no Au anomalies have been identified.

The source for the South Indian Lake - Missi Rapid dispersal train (zone 4) is not well defined. As-enriched debris may represent sulphide mineralization within metasediments (unit 3) and metagreywackes (unit 2) outcropping south of Missi Rapid (Gale et al., 1980). The head of the train is located just south of a thin band of volcanogenic sediments that contain massive sulphide strata (Gale et al., 1980). The southward extension of this train in the South Indian Lake area is tenuous, but the lack of an obvious source in this area, suggests that elevated As concentration may be the result of dispersal from the northeast.

The zone of elevated As concentration in the Sherridon area (zone 5) again reflects sulphide mineralization associated with the contact between metasediments (unit 3) and metagreywacke (unit 2) along the southern margin of the Kisseynew gneiss belt. Au and Cu anomalies are also observed within this region. Southward extension of this zone is unknown. Comparison with detailed bedrock mapping (Schledewitz, 1988a, 1988b), suggests a correlation between elevated As and Cu concentration and the distribution of quartzofeldspathic gneisses of the Missi Metamorphic Suite.

The only other geochemical evidence for glacial dispersal on a local scale was observed at Osik Lake, where till enriched in both Ni and Cr (Figure 2) extends approximately 30 km down-ice form a previously unknown ultramafic source body, located within Osik Lake (DiLabio and Kaszycki, 1988).

Local Bedrock Trends

In general, regional geochemical anomalies exhibit irregular patterns thought to reflect areas of mineralization within regional lithologic units. On a local scale, these regional anomalies represent higher background concentrations associated with potentially mineralized zones. The lack of dispersal associated with anomalies may be the result of a number of factors including, rapid dilution of debris in the down-ice direction, small anomaly to background ratio, and size aspect and erodibility of source area. Regional geochemical anomalies have been grouped into zones. Anomalous zones are identified by clusters of samples containing anomalous concentrations (>95th percentile) of a specific trace element. However, not all samples within zone boundaries are anomalous with respect to a given element, and in cases of a zone defined by multi-element anomalies, not all samples are anomalous with respect to all elements.

The distribution of regional Au anomalies (Figure 7) reflects both regional variations in bedrock lithology, as well as zones within lithic units containing elevated Au concentrations. Referring to Table 1d, it is evident that definition of Au anomalies as >95th percentile concentration based on the entire data population, results in over representation of anomalies in areas dominated by terrestrial metasediments. Interpretation of anomalous zones therefore, must take into account regional variations in background concentration with respect to bedrock lithology, and 95th percentile values for each lithic type.

Two different types of lithologic setting for Au anomalies can be identified:

1) anomalies occurring within terrestrial metasediments (unit 3), and/or near the contact between metasediments and metagreywacke (unit 2);

2) anomalies occurring at or near contacts between units 2 or 3, and felsic intrusives (unit 4b).

Six zones of anomalous Au concentration have been identified. The largest of these (zone 1) encompasses the western extent of Sickle Group rocks (unit 3) within the region. Most samples within this zone contain Au concentrations ranging from 80th to 90th percentile values, reflecting the higher background concentration for Au observed in till derived from terrestrial metasedimentary rocks. The 95th percentile value for the metasediment subgroup, suggests that only samples containing >30 ppb Au should be considered truly anomalous within this zone. Au anomalies are scattered, but in general, occur near the contact between metasediment and intrusive lithologies, possibly indicating a tectonically controlled depositional setting.

Au anomalies within zone 2 (Wheatcroft Lake) occur within metagreywacke (unit 2). 95th percentile values for Au within till sampled over this lithologic unit suggest that samples containing Au in concentrations >10 ppb may be considered anomalous. Au anomalies are scattered, occurring south of the only known Au showing within the region (Barry, 1965). When compared with 1:50,000 bedrock maps for the area it can be seen that approximately 50% of all Au anomalies are located near the margin of felsic intrusives, again suggesting a tectonically controlled mineralization (Kaszycki et al., 1988).

Within zones 3 and 4, Au anomalies appear to coincide with the contact between units 2 and 3. Bedrock mapping at 1:50,000 within these regions does not indicate any association with intrusive lithologies (Schledewitz, 1988a; Baldwin et al., 1979), suggesting that Au may be sediment-hosted. However, faulting is common along these lithologic contacts, and Au may be associated with lithostratigraphically controlled fault zones. Detailed follow-up sampling is presently underway in the Kississing Lake area (zone 4) (Gobert and Nielsen, in prep; Nielsen and Gobert, 1988) in order to define more clearly the nature and possible source(s) for Au and associated As and Cu anomalies within this region.

Zone 5 corresponds to the Rusty Lake Greenstone Belt. Au anomalies are scattered throughout this region. Comparison with detailed mapping (Baldwin, 1982, 1988; Steeves and Lamb, 1972) does not reveal any systematic mode of occurrence. Detailed sampling has been carried out in the Ruttan area, located in the central part of zone 5 (Nielsen, 1985, 1986a, 1987), and in the Darrol Lake area, located in the southeastern part of zone 5 (Nielsen, 1987; Nielsen and Gobert, 1988; and Kaszycki. 1988). Geochemical results from these studies have not yet been published in full. In the Ruttan area, a well defined Au anomaly is centred on the Vol fault, with four samples containing >20 grains of visible gold per 5 kg sample (Nielsen, 1986a; pers. com., 1987). Till in this region is also anomalous with respect to As. The delicate nature of most Au grains indicates that they are locally derived and have not undergone extensive glacial transport, suggesting that Au mineralization in this area may be fault controlled. In the Darrol Lake area, the distribution of Au in till is sporadic, although 75% of Au-bearing samples occur within till overlying mafic metavolcanic rocks, or near the contact between mafic and felsic units (E. Nielsen, pers. com., 1988). Most gold grains are abraded and Au in till likely reflects regional background.

Zone 6 is located north of the Lynn Lake Greenstone Belt in the Barrington Lake area. The largest Au concentrations in this zone occur within felsic intrusives north of the greenstone belt. Using the 95th percentile value for till derived from intrusive lithologies (8 ppb), four samples, containing anomalous Au ranging up to 16 ppb, define the head of what appears to be a dispersal train trending approximately 20 km to the southwest at ~210°. The tail of the train crosses onto the Lynn Lake greenstone belt, forming three plumes characterized by Au concentrations of 6 - 7 ppb, or within the 85 to 90th percentile range for the intrusive category. The westernmost plume encompasses the Farley Lake gold deposit. At this site, Au is preferentially concentrated in the fine silt size fraction and Au concentration in the minus 200 mesh (<74µm) till fraction averages 12 ppb (Brereton et al., 1988). It is possible that Au concentration within the tail of the train reflects contribution from this and similar local mafic extrusive sources within the train (Baldwin et al., 1985), however, the trend of the plumes, plus the systematic decrease in Au concentration down-ice suggests dispersal by glacial ice. A source for Au near the head of the train is unknown, but may be associated with faults or fracture zones within intrusive bodies, or contacts with unmapped metasedimentary or volcanic lithologies within the region. Detailed surface till sampling within the Farley lake area (Nielsen and Graham, 1985) identified several scattered Au anomalies within the heavy mineral fraction of till, but the <63µm fraction was not analyzed for Au and direct comparison with results of regional surveys is not possible.

Multi-Element Trends

Multi-element combinations of regional geochemical anomalies have been recognized by superimposing the distribution of anomalies for several trace elements. The result is a map illustrating the co-occurrence of regional anomalies (Figure 8). Multi-element trends encompass both local dispersal and local bedrock trends. For example, the large area of As-enriched till forming the Wheatcroft Lake dispersal train is characterized by a sub-region near the head of the train that is anomalous with respect to Cu, Zn, U, and Au (zone 1). Only As is sufficiently enriched within bedrock over a large enough area to form a dispersal train. Other trace element anomalies represent areas of potential mineralization. Cu, Zn anomalies likely reflect sediment hosted disseminated sulphide mineralization within metagreywacke. Au, on the other hand, is more closely related to felsic intrusives, possibly suggesting a tectonically controlled source (Kaszycki et al., 1988).

Other multi-element anomalies include:

Zone 2: Ni, Cu, Au, over the Rusty Lake Greenstone Belt. Detailed sampling has been carried out within the Ruttan and Darrol Lake areas (Nielsen, 1987, 1986a, 1986b);

Zone 3: Cu, As, Au, associated with sulphide mineralization near the contact between metagreywacke and metasediments in the Sherridon - Kississing Lake area. Follow-up sampling at a scale of 1:50,000 is presently being carried out (Gobert and Nielsen, in prep; Nielsen and Gobert, 1988).

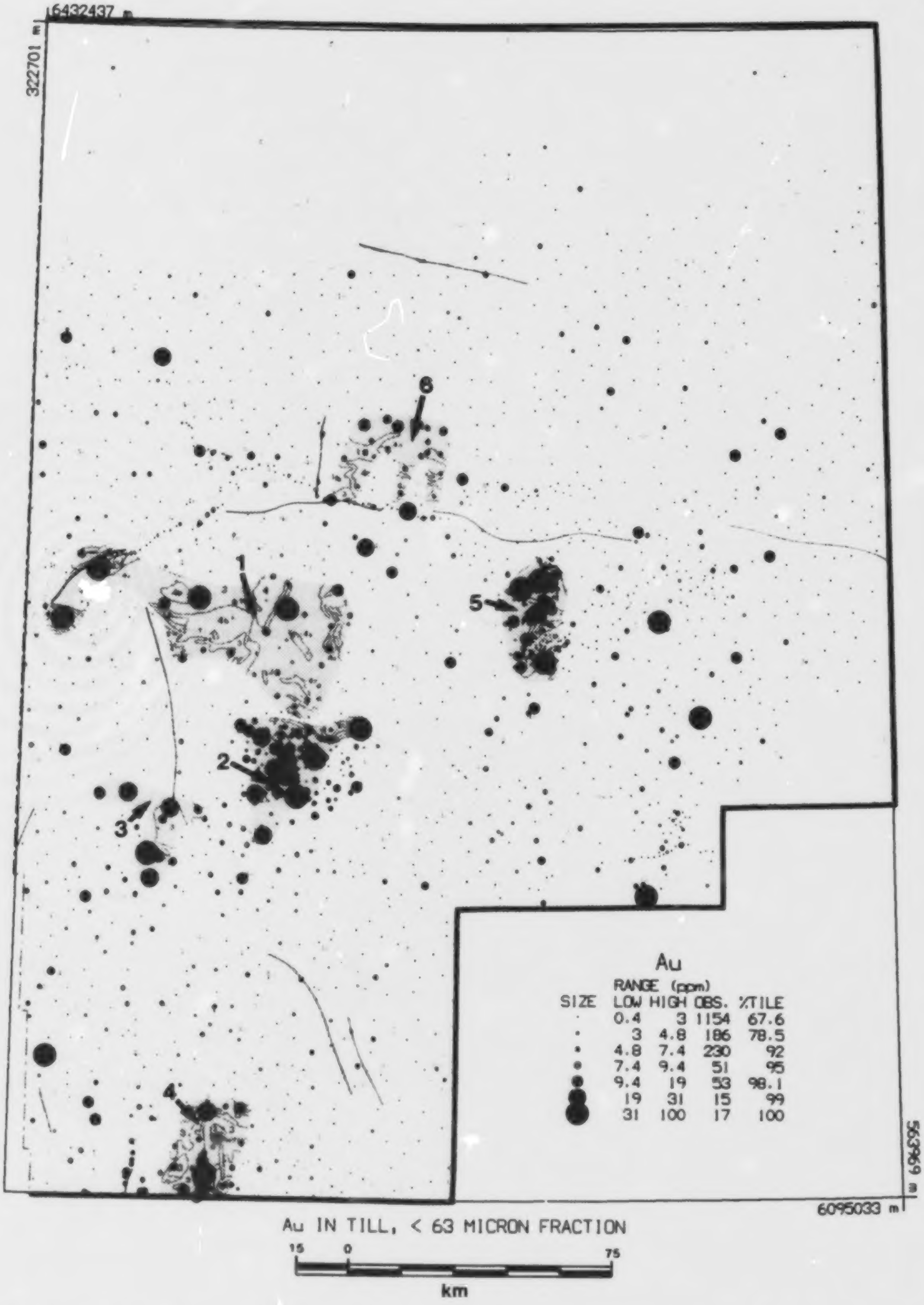
6432437 m
322701 m
8
1
5
2
3
4
Au
RANGE (ppm)
SIZE LOW HIGH OBS. %TILE
· 0.4 3 1154 67.6
• 3 4.8 186 78.5
• 4.8 7.4 230 92
● 7.4 9.4 51 95
● 9.4 19 53 98.1
● 19 31 15 99
● 31 100 17 100
563969 m
6095033 m
Au IN TILL, < 63 MICRON FRACTION
15
0
75
km

Figure 7. Regional distribution of Au in till, in relation to bedrock lithology. Shaded areas represent anomalous zones. Bedrock geology from Manitoba Mineral Resources Division, Map 79-2. Refer to Figure 3. for explanation of bedrock units.

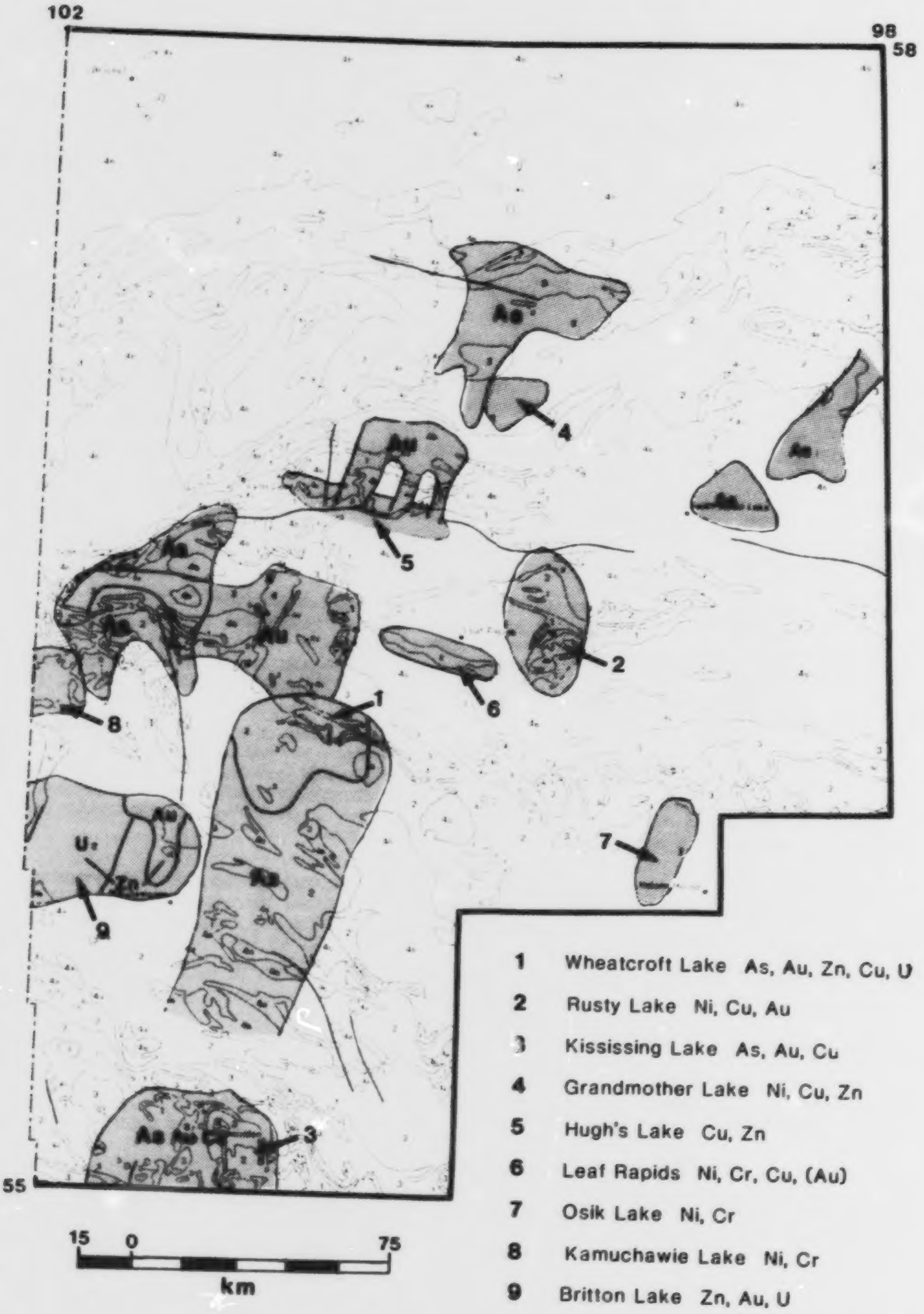
102
98
58
55
As
Au
As
As
As
As
Au
As
U
Zn
Au
As
Au
1
2
3
4
5
6
7
8
9
15
0
75
km
1 Wheatcroft Lake As, Au, Zn, Cu, U
2 Rusty Lake Ni, Cu, Au
3 Kississing Lake As, Au, Cu
4 Grandmother Lake Ni, Cu, Zn
5 Hugh's Lake Cu, Zn
6 Leaf Rapids Ni, Cr, Cu, (Au)
7 Osik Lake Ni, Cr
8 Kamuchawie Lake Ni, Cr
9 Britton Lake Zn, Au, U

Figure 8. Distribution of multi-element anomalies in till (shaded). Bedrock geology from Manitoba Mineral Resources Division, Map 79-2. Refer to Figure 3. for explanation of bedrock units.

Zone 4: Ni, Cu, Zn associated with biotite gneiss of metasedimentary origin (metagreywacke) in the Grandmother Lake area;

Zone 5: Cu, Zn, associated with the Johnson shear along the eastern extension of the Lynn Lake Greenstone Belt. Detailed work within parts of this region have been carried out by Nielsen (1985);

Zone 6: Ni, Cr, Cu, (Au), associated with greywacke and calc-silicate rock just south of Leaf Rapids;

Zone 7: Ni, Cr, associated with glacial dispersal of ultramafic debris from Osik Lake (DiLabio and Kaszycki, 1988);

Zone 8: Ni, Cr, associated with the contact between metagreywacke (unit 2) and other metasediments (unit 3) in the Kamuchawie Lake area;

Zone 9: Zn, Au, U, associated with metagreywacke (unit 3) in the Britton Lake area.

CONCLUSIONS AND RECOMMENDATIONS

1) Till composition varies laterally across the study area, ranging from sandy shield derived till of Keewatin provenance in the west, to silty calcareous till of Hudson Bay provenance in the east. These provenance related shifts in till composition have significantly influenced regional variations in trace element concentration and the resolution of geochemical anomalies.

2) Local dispersal patterns (10's to 100 km) trend 200√-210√, parallel to Main Late Wisconsinan ice flow. Dispersal at this scale has not been affected by late glacial shifts in ice flow. It is possible however, that at a detailed scale (<1km) dispersal patterns may have been influenced by short-lived deglacial ice flow patterns and/or deflection of ice flow around bedrock obstructions.

3) Detailed studies indicate that the down-ice transport of material derived from areas of known sulphide mineralization cannot be traced farther than 1 - 2 km (Nielsen, 1987; Nielsen and Fedikow, 1987, 1986; Nielsen and Graham, 1985). Based on these observations it is apparent that the sampling density employed in this study (7 - 8 km spacing) is unlikely to result in the intersection of these small dispersal trains. Rather, regional anomalies identify geochemically enriched bedrock units with potential for hosting small volcanogenic sulphide bodies, rather than the small sulphide bodies themselves.

4) Regional geochemical trends reflect the combined influence of till provenance and regional lithologic trends. Calcareous tills are enriched in Mn and Zn and depleted in Cr, Au, and U, suggesting that Paleozoic debris may significantly mask the geochemical signature of local bedrock lithologies for certain trace elements. In addition, interpretation of regional anomalies must take into account variations in background concentration with respect to regional bedrock lithologies, and 95th percentile values for each rock type.

5) At a local scale (several to 10's of km), geochemical patterns are manifest as zones of anomalously high trace element concentration, reflecting potentially mineralized areas within regional bedrock lithologies. These patterns may be elongated in a direction parallel to ice flow, reflecting glacial erosion and transport of mineralized debris. In these cases the areal distribution of geochemically enriched debris may far exceed that of mineralized source rocks. More commonly however, local anomalies exhibit irregular patterns closely reflecting the outcrop area of metal-enriched source rocks.

6) Well defined dispersal patterns of As-enriched debris correlate with zones of disseminated sulphide mineralization, commonly located at the contact between terrestrial metasediments (unit 3) and underlying metagreywacke (unit 2) and/or metavolcanics (unit 1). It is significant however, that extensive As-enrichment in till occurs only at specific sites along this contact, suggesting unusual mineralogical conditions possibly associated with base metal and/or Au mineralization within these areas.

7) The distribution of regional Au anomalies reflects both regional variations in bedrock lithology, as well as zones of elevated Au concentration within rock units Two different types of Au anomaly can be identified: 1) those occurring within terrestrial metasediments (unit 3), and/or near the contact between metasediments and metagreywacke (unit 2), possible reflecting stratabound Au mineralization; and 2) those occurring at or near the contacts between units 2 or 3, and felsic intrusives (unit 4b), possibly reflecting higher background associated with tectonically controlled mineralization.

8) Nine areas containing multi-element regional geochemical anomalies have been identified. These trends encompass both local glacial dispersal and local bedrock trends, and may represent an important step toward identification of the nature and scale of geochemical haloes associated with base metal and Au mineralization within the region. To date, detailed follow-up sampling has been, or is presently being carried out in the Wheatcroft Lake area, Kississing Lake area and the Rusty Lake area . More detailed work is required however, to adequately identify the nature of mineralization associated with these anomalies, specifically that associated with large As anomalies.

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SURFICIAL GEOLOGY MAPPING, MANITOBA, NORTH OF 52N

Martin Clark
Terrain Sciences Division
Geological Survey of Canada

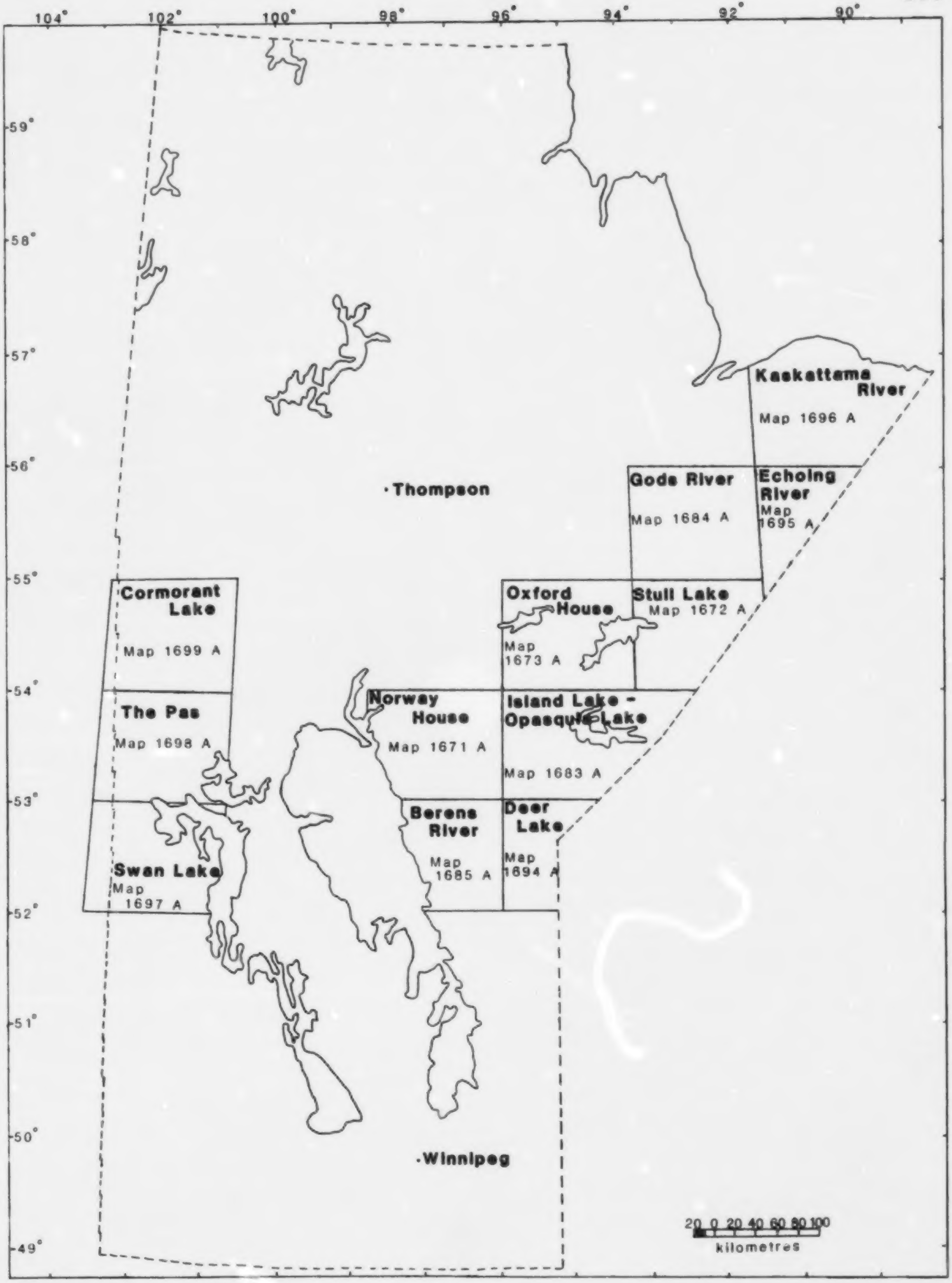
Project C.5.1.1. was designed to map the regional distribution of Quaternary sediments as an aid to the interpretation of glacial history and as an overview for scientists concerned with site-specific studies. The project has contributed three separate types of scientific output. The primary task, to produce surficial geology maps at 1:250,000 scale, has been accomplished through the publication of twelve maps. Subsidiary maps at different scales in areas of interest have constituted a second form of scientific output, while a study into the suitability of various types of satellite imagery for mapping surficial geology has resulted in a paper due to be published shortly.

The production of twelve A-series maps represents the completion of surficial geology coverage at 1:250,000 scale for all of Manitoba north of 52 N. The maps have a common legend and each map is accompanied by descriptive notes and an inset map of potential aggregate resources. The mapping of surficial landforms indicative of sediment type was accomplished by analysis of aerial photographs and satellite imagery. The interpreted information was then verified by ground checking selected sites. Completed maps offer useful information on regional ice flow directions and distribution of glacial and non-glacial sediments, providing a basis for drift prospecting and boulder tracing operations. From an engineering construction perspective, relative stability of local surface sediments can be inferred from the surficial geology, and the availability of accessible aggregate material can be detected from the insert maps.

Areas of specific interest have been mapped at scales different from 1:250,000 and released as open file publications. Four surficial geology maps in the vicinity of the mineral-rich Flin Flon-Snow Lake greenstone belt have been published at 1:125,000 scale as an aid to drift prospecting and mineral exploration in that region. For northeastern Manitoba, a synthesis of nine, 1:250,000 maps has been compiled at 1:500,000 scale to provide a regional overview of the area and to complement published maps at the same scale in other parts of northern Manitoba. These maps are found in: Dredge et al, GSC memoir 418, and, Klassen, GSC memoir 419.

A third aspect of the project took the form of investigations into cost-effective alternatives to aerial photographs for interpretation of surficial geology. The objective of this study was to show that surficial geology maps at a regional scale (1:250,000) produced by analysis of satellite imagery can be as detailed and accurate as maps produced by interpretation of conventional aerial photographs. Four types of remotely sensed imagery (Return Beam Vidicon, Multispectral Scanner, Thematic Mapper, and Large Format Camera) were viewed using the PROCOM - 2 optical transfer device and tested for their suitability for the interpretation of surficial geology. Each imagery type was analyzed for each geological map unit and was subjectively judged on its overall value. The study concludes that the Large Format Camera and Thematic Mapper imagery can be cost-effective in producing accurate surficial geology maps at a regional scale of similar detail to those interpreted from aerial photographs.

Overall, the impact of project C.5.1.1. is to add to the knowledge of the origin, distribution, and properties of Quaternary materials in northeastern and western Manitoba and to promote a better understanding of the evolution and current modification of terrain conditions. This information is essential to various aspects of land use planning and the prediction of hazards from man-made or natural causes. In addition, the satellite mapping study offers an improvement in mapping techniques and methods to the point where this imagery can augment, and possibly replace, aerial photographs for mapping surficial geology in the future.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Kaskattama River
Map 1696 A
Gods River
Map 1684 A
Echoing River
Map 1695 A
Thompson
Cormorant Lake
Map 1699 A
Oxford House
Map 1673 A
Stull Lake
Map 1672 A
The Pas
Map 1698 A
Norway House
Map 1671 A
Island Lake - Opasquia Lake
Map 1683 A
Berens River
Map 1685 A
Deer Lake
Map 1694 A
Swan Lake
Map 1697 A
Winnipeg
20 0 20 40 60 80 100
kilometres

Figure 1. Surficial geology maps completed under the 1984-89 Mineral Development Agreement.

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APPENDIX I

LIST OF OUTPUTS
produced by the
GEOLOGICAL SURVEY OF CANADA
during the
CANADA-MANITOBA MINERAL DEVELOPMENT AGREEMENT (1984-1989)

Outputs have been divided into:

a) Publications   b) Open Files   c) Posters   d) Oral Presentations   e) Theses

1.1 PRECAMBRIAN INVESTIGATIONS

C.1.1.1: Mineralized alteration zones, southern Churchill Province (E. Froese)

a) Publications

1984-85

Barham, B. A., The geology of the Nicoba Zn-Cu deposit, Lynn Lake, Manitoba: Preliminary results; in Current Research, Part B, Geological Survey of Canada, Paper 85-1B, p. 499-510, 1985.

Froese, E., Anthophyllite-bearing rocks in the Flin Flon - Sherridon area, Manitoba; in Current Research, Part B, Geological Survey of Canada, Paper 85-1B, p. 541-546, 1985.

1985-86

Barham, B.A. and Froese, E., Geology of the New Fox alteration zone, Laurie Lake, Manitoba; in Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 827-835, 1986.

Zaleski, E., Geology of the Linda volcanogenic massive sulphide deposit, Snow Lake, Manitoba; in Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 15-20, 1986.

1987-88

Froese, E., Metamorphosed alteration zones (Project C.1.1.1); in Report of Field Activities 1987, Manitoba Energy and Mines , Report GSC-1, p. 168, 1987.

Zaleski, E., and Halden, N.M., Reconstruction of synvolcanic alteration associated with the Linda massive sulphide deposit, Snow Lake, Manitoba; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 73-81, 1988.

1988-89

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c) Posters

1985-86

Barham, B.A., Alteration associated with the New Fox deposit, Lynn Lake, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

Bristol, C. and Froese, E., Alteration studies at the Osborne Lake Mine, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

Zaleski, E., Alteration study of the Linda deposit, Snow Lake, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

1986-87

Barham, B.A., Cordierite-orthoamphibole-garnet rocks of the New Fox alteration zone, Laurie Lake, Manitoba, at the GAC/MAC/CGU Joint Annual Meeting, Ottawa, May 21, 1986; abstract published in GAC/MAC/CGU Program with Abstracts, v. 11, p. 43, 1986.

Zaleski, E., The Linda hydrothermal system, Snow Lake area, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986, and at the Geological Survey of Canada Current Activities Forum, Ottawa, January 20-21, 1987.

1987-88

Leroux, M., The garnet-cordierite-anthophyllite mineralogy of the Star Lake area, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20, 1987.

1988-89

Ashton, K.E. and Froese, E., Could the Sherridon Group at Sherridon be a high-grade equivalent of the Amisk Group?; in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-18, p. 183-184, 1988.

d) Oral Presentations

1986-87

Bristol, C.C. and Froese, E., Geology of the Osborne Lake orebody and the effects of high-grade metamorphism on its associated alteration, at the GAC/MAC/CGU Joint Annual Meeting, Ottawa, May 18, 1986; abstract published in GAC/MAC/CGU Program with Abstracts, v. 11, p. 48, 1986.

1987-88

Froese, E., Metamorphism of sulphide-bearing rock, at the 16th Annual McGill Adams Club Symposium, Ore Deposits in Metamorphosed Terrains, 1987; abstract published in symposium program with abstracts, p. 1-2, 1987.

1988-89

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1989-90

Zaleski, E., Relationship between deformation and metamorphism at the Linda volcanogenic massive sulphide deposit, Snow Lake, Manitoba, at the GAC/MAC/CSPG Joint Annual Meeting, St. John's, May 25, 1988; abstract published in GAC/MAC/CSPG Program with Abstracts, v. 13, p. A138, 1988.

e) Theses

1987-88

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1989-90

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C.1.1.2 Metamorphism in the Lynn Lake-Laurie Lake area (T.M. Gordon)

a) Publications

1984-85

Jackson, S.L. and Gordon, T.M., Metamorphism and structure of the Laurie Lake region, Manitoba; in Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 753-760, 1985.

1985-86

Jackson, S.L. and Gordon, T.M., Metamorphic studies in the transition zone between the Lynn Lake greenstone belt and the Kisseynew gneiss belt, Laurie Lake, Manitoba; in Current Research, Part B, Geological Survey of Canada, Paper 86-1B, 539-546, 1986.

1987-88

Gordon, T.M., Alteration studies: Kisseynew Gneiss Belt (Project C.1.1.2): Progress Report; in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-2, p. 168, 1987.

1988-89

Jackson, S.L., Alteration zones, structure and metamorphism of the Laurie Lake area; in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-17, p. 178-182, 1988.

1989-90

Jackson, S.L., Extension of Wohl's ternary asymmetric solution model to four and n components; American Mineralogist, v. 74, no. 1 & 2, p. 14-17, 1989.

c) Posters

1985-86

Jackson, S.L., Pressure-temperature conditions of metamorphism in the Laurie Lake region, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

1986-87

Jackson, S.L., Metamorphic studies in the transition zone between the Lynn Lake greenstone belt and the Kisseynew gneiss belt, Laurie Lake, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

d) Oral Presentations

1986-87

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1987-88

Jackson, S.L., Mineral equilibria applied to the Lynn Lake metavolcanic/Kisseynew metasedimentary belt transition zone, at the Western Inter-university Geological Conference, London, Ontario, January 1988; abstract published in program with abstracts, p. 19, 1987.

1989-90

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e) Theses

1988-89

Jackson, S.L., Alteration zones, structure and metamorphism of the Laurie Lake area, Manitoba; unpublished Ph.D. thesis, Queen's University, Kingston, 204 pp., 1988.

C.1.1.3 U/Pb geochronology, Churchill Province (T. Gordon)

a) Publications

1987-88

Baldwin, D.A., Syme, E.C., Zwanzig, H.V., Gordon, T.M., Hunt, P.A. and Stevens, R.D., U-Pb zircon ages from the Lynn Lake and Rusty Lake metavolcanic belts, Manitoba: Two ages of Proterozoic magmatism; Canadian Journal of Earth Sciences, v. 24, no. 5, p. 1053-1063, May 1987.

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1988-89

Bailes, A.H., Gordon, T.M. and Hunt, P.A., U-Pb zircon geochronology of the Richard Lake tonalite, a possible synvolcanic pluton in the Snow Lake area; in Report of Field Activities 1988, Manitoba Energy and Mines, Report GS-10, p. 63-65, 1988.

Gordon, T.M., Geochronology in the Churchill Province (Project C.1.1.3); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-2, p. 170-172, 1988.

1989-90

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d) Oral Presentations

1984-85

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1986-87

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1987-88

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C.1.1.4 U/Pb geochronology, N.W. Superior Province (T. Gordon)

a) Publications

1984-85

Krogh, T., Heaman, L., Machado-Fernandes, N. and Weber, W., U/Pb geochronologic studies, Thompson belt and northwestern Superior Province; in Report of Field Activities 1984, Manitoba Energy and Mines, Report GS-31, p. 119, 1984.

1985-86

Krogh, T., Heaman, L., Machado, N. and Weber, W., U-Pb geochronology program: Thompson belt and Pikwitonei domain; in Report of Field Activities 1985, Manitoba Energy and Mines, Report GS-36, p. 183-184, 1985.

1986-87

Krogh, T., Heaman, L., Machado, N., Davis, D. and Weber, W., U-Pb geochronology program: Northern Superior Province; in Report of Field Activities 1986, Manitoba Energy and Mines, Report GS-36, p. 178-180, 1986.

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1988-89

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d) Oral Presentations

1986-87

Heaman, L., Machado, N., Krogh, T. and Weber, W., Preliminary U-Pb zircon results from Pikwitonei granulite terrain, Manitoba, at the GAC/MAC/CGU Joint Annual Meeting, Ottawa, May 21, 1986; abstract published in GAC/MAC/CGU Program with Abstracts, v. 11, p. 79, 1986.

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1987-88

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C.1.1.5 Structural studies, Thompson Belt (E. Froese)

a) Publications

1985-86

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1987-88

Froese, E., Structural studies in the Thompson Belt (Project C.1.1.5); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-4, p. 168, 1987.

1989-90

Fueten, F. and Robin, P.Y.F., (in press), Structural petrology along a transect across the Thompson Belt, Manitoba: Dip-slip at the western Churchill-Superior boundary; Canadian Journal of Earth Sciences, 1989.

Pearce, G.W. and Fueten, F., An intensive study of magnetic susceptibility anisotropy of amphibolite layers of the Thompson belt, central Manitoba; Tectonophysics, v. 162, p. 315-331, 1989.

c) Posters

1986-87

Fueten, F. and Robin, P.Y.F., Deformation in the Thompson belt, Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 20-21, 1987.

1987-88

Fueten, F., Structural studies in the Thompson Belt, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

d) Oral Presentations

1986-87

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Fueten, F., Deformation in the Thompson belt: Presentation of data, at the Meeting of the Trans-Hudson Orogen Lithoprobe Group, Winnipeg, April 1986.

1987-88

Fueten, F. and Robin, P.Y.F., Deformational history and quartz fabrics of Paint Lake, Thompson belt, central Manitoba, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987, and at the Central Canada Geological Conference, University of Western Ontario, London, Ontario, 1988.

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1989-90

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C.1: CORE DRILLING

C.1.2.1 Sub-Paleozoic compilation/core drilling (T. Gordon)

a) Publications

1987-88

Blair, B.B., Project Cormorant: Interpretation of sub-Phanerozoic geology (Project C.1.2.1): Progress Report; in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-5, p. 168, 1987.

1988-89

Blair, B., Weber, W., Kornick, L.J. and Gordon, T.M., Project Cormorant: Interpretation of Sub-Paleozoic geology of the Cormorant Lake map area from geophysical and drill core data; Geoscience Canada, v. 15, no. 2, p. 98-100, 1988.

b) Open Files

1986-87

Taiga Consultants Limited, Sub-Paleozoic geology of the Cormorant Lake map area (63K), Manitoba; Geological Survey of Canada, Open File 1381, 11 p., 1 map at 1:250,000 scale, November 19, 1986.

c) Posters

1986-87

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1987-88

Blair, B. and Kornik, L., Sub-Phanerozoic geology of the Cormorant Lake map area, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

1988-89

Dugal, J.B., Project Cormorant: Interpretation of Sub-Paleozoic geology south of Flin Flon - Snow Lake (Project C.1.2.1), at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988; abstract published in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-3, p. 172, 1988.

d) Oral Presentations

1987-88

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Kornik, L.J., Blair, B.B. and Gordon, T.M., Aeromagnetic interpretations as aids to exploration of the buried Canadian Shield, Manitoba-Saskatchewan boundary area, at the 56th Annual General Meeting of the Prospectors and Developers Association of Canada, Toronto, March 9, 1988.

Weber, W. and Gordon, T.M., Project Cormorant: An attempt to delineate Precambrian basement geology beneath Paleozoic carbonates south of Flin Flon - Snow LAke, at the GAC/MAC Joint Annual Meeting, Saskatoon, May 26, 1987; abstract published in GAC/MAC Program with Abstracts, v. 12, p. 100, 1987.

2.1 MINERAL INVESTIGATIONS

C.2.1.1 Flin Flon-Snow Lake metallogeny (J.M. Franklin)

a) Publications

1984-85

Galley, A.G., Ames, D. and Franklin, J.M., Preliminary investigation of gold occurrences in the Flin Flon - Snow Lake belt, Manitoba and Saskatchewan; in Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 761-771, 1985.

1986-87

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Galley, A.G., Ziehlke, D.V., Franklin, J.M., Ames, D.E. and Gordon, T.M., Gold mineralization in the Snow Lake-Wekusko Lake region, Manitoba; in Proceedings of the Gold in the Western Shield Symposium, edited by L.A. Clark and D.R. Francis, CIM Special Volume 38, p. 379-398, 1986.

1987-88

Galley, A.G., Flin Flon-Snow Lake metallogeny (Project C.2.1.1); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-6, p. 169, 1987.

Galley, A.G., Ames, D.E., and Franklin, J.M., Geological setting of gold mineralization in the Elbow Lake region; in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-19, p. 175-177, 1987

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1988-89

Galley, A.G., Flin Flon - Snow Lake Metallogeny (project C.2.1.1); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-4, p. 172-174, 1988.

b) Open Files

1988-89

Galley, A.G., Ames, D.E., and Franklin, J.M., Geological setting of gold mineralization, Snow Lake, Manitoba; Geological Survey of Canada, Open File 1700, 1 map at, 1:5000 scale, February, 1988.

Skirrow, R.G. and Franklin, J.M., Semiconformable hydrothermal alteration below the Chisel Lake Zn-Cu massive sulphide Deposit, Snow Lake, Manitoba; Geological Survey of Canada, Open File 1986, two 1:2000 scale maps, March 1989.

c) Posters

1984-85

Galley, A.G., Franklin, J.M. and Ames, D., Gold investigations, Flin Flon - Snow Lake belt, Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 22-24, 1985.

1986-87

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Galley, A.G. and Franklin, J.M., Alteration and gold mineralization at the Nor-Acme Mine, Snow Lake, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986

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Skirrow, R., Deep footwall alteration zones beneath the Chisel Lake massive sulphide deposit, Snow Lake, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

1988-89

Galley, A.G. and Bailes, A.H., Geology of the Chisel Lake open pit, Snow Lake, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

d) Oral Presentations

1984-85

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1985-86

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1988-89

Galley, A.G., Some aspects of gold metallogeny in the southern Churchill Province, at the meetings of the Flin Flon and Lynn Lake local sections of the Canadian Institute of Mining and Metallurgy (CIM), February 1989, at the Saskatoon CIM local section meeting, April 1989, and at the Manitoba Energy and Mines Geological Services Branch, February 1989.

e) Theses

1987-88

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C.2.1.2 Bissett structural studies (K.H. Poulsen)

a) Publications

1985-86

Poulsen, K.H., Auriferous shear zones with examples from the western Shield; in Proceedings of the Gold in the Western Shield Symposium, edited by L.A. Clark and D.R. Francis, CIM Special Volume 38, p. 86-103, 1986.

1986-87

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1987-88

Poulsen, K.H., Structural and alteration studies, Bissett area (Project C.2.2.1); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-7, p. 169, 1987.

1988-89

Brommecker, R., Poulsen, K.H. and Hodgson, C.J., Preliminary report on the structural setting of gold at the Gunnar mine in the Beresford Lake area, Uchi Subprovince, southeastern Manitoba; in Current Research, Part C, Geological Survey of Canada, Paper 89-1C, p. 325-332, 1989.

Poulsen, K.H., Structural and alteration studies, Bissett area (Project C.2.1.2); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-5, p. 174, 1988.

Poulsen, K.H., Brommecker, R., Green, S.B., Baker, K.A., Lin Baoquin, Shang Ling, Shan Ershu, Zhang LiDong, Diamond, L. and Marshall, D., Contrasts in setting and style of gold deposits in two Archean terranes: Rice Lake District, Canada, and western Liaoning District, China; in Current Research, Part C, Geological Survey of Canada, Paper 89-1C, p. 121-126, 1989.

c) Posters

1984-85

Lau, S. and Brisbin, W., Vein geometry of the San Antonio Mine, at the Manitoba Energy and Mines, Annual Open House, Winnipeg, November 15, 1984, and at the Geological Survey of Canada, Current Activities Forum, Ottawa, January 22-24, 1985.

1985-86

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1986-87

Ames, D.E. and Poulsen, K.H., Carbonatization of a metamorphosed layered mafic intrusion, San Antonio Mine, Bissett, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

Lau, S., Brisbin, W.C., Poulsen, K.H. and Ames, D.E., Structural geology of the San Antonio gold mine, southeastern Manitoba, at Gold'86 International Symposium on the Geology of Gold Deposits, Toronto, September 28-October 1, 1986; abstract published in Gold'86, Poster Paper Abstracts, edited by A.M. Chater, p. 92-95, 1986.

1987-88

Ames, D.E. and Poulsen, K.H., The San Antonio gold deposit, southern Manitoba, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

1988-89

Ames, D.E., Zonation of wallrock alteration at the San Antonio Mine, Bissett, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

Brommecker, R. and Poulsen, K.H., Structural setting of the Gunnar mine, Beresford Lake, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

d) Oral Presentations

1985-86

Poulsen K.H., Auriferous shear zones with examples from the western Shield, at the Canadian Institute of Mining and Metallurgy Symposium on Gold in the Western Shield, Saskatoon, September 1985.

1987-88

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1987-88

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1989-90

Ames, D.E., Franklin, J.M. and Froese, E., Zonation of wallrock alteration at the San Antonio gold mine, Bisset Manitoba, at the 91st Annual General Meeting of the Canadian Institute of Mining and Metallurgy, Quebec City, May 1, 1989; abstract published in CIM Bulletin, v. 82, no. 923, p. 67-68, 1989.

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e) Theses

1988-89

Tirschmann, P.A., Physical volcanology and sedimentology of part of the Archean Rice Lake Group, Rice Lake greenstone belt, southeastern Manitoba; unpublished B.Sc. thesis, University of Manitoba, Winnipeg, 1987.

1988-89

Ames, D.E., Stratigraphy and alteration of gabbroic rocks near the San Antonio gold mine, in the Rice Lake area, southeastern Manitoba; unpublished M.Sc. thesis, Carleton University, Ottawa, 1988.

Lau, M.H.S., Structural geology of the vein system in the San Antonio gold mine, Bissett, Manitoba, Canada; unpublished M.Sc. thesis, University of Manitoba, Winnipeg, 1988.

C.2.1.3 Agassiz remote-sensing research (A.N. Rencz)

a) Publications

1987-88

Rencz, A., Agassiz remote-sensing (Project C.2.1.3); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-8, p. 170, 1987.

1988-89

Rencz, A.N., Agassiz remote sensing (Project C.2.1.3); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-6, p. 174, 1988.

1989-90

Singh, V., Moon, W.M., Fedikow, M. and Rencz, A.N., (in press), Analysis of multi-media data for exploration: An example from northern Manitoba; Proceedings of the Annual Meeting of the Canadian Society of Exploration Geophysicists, Calgary, June 1989.

b) Open Files

1988-89

Singh, V., Moon, W.M. and Fedikow, M., Agassiz metallotect: Application of MEIS-2 for biogeochemical remote sensing and geochemical exploration, Lynn Lake area, Manitoba; Geological Survey of Canada, Open File 1994, 74 p., March 1989.

c) Posters

1987-88

Kettler, D., Anderson, D. and Fedikow M., Application of remote sensing to the study of the Agassiz metallotect, at the Winnipeg Section Meeting of the Canadian Institute of Mining and Metallurgy, April 1987.

Moon, W.M. and Rencz, A.N., Agassiz remote sensing, at the Canadian Institute of Mining and Metallurgy Annual Branch Meeting, Winnipeg, April 1987.

1989-90

Singh, V., Moon, W.M., Fedikow, M. and Rencz, A.N., Analysis of multi-media data for exploration: An example from northern Manitoba, at the Annual Meeting of the Canadian Society of Exploration Geophysicists, Calgary, June 1989.

2.2 METALLOGENY OF MAFIC-ULTRAMAFIC ROCKS

C.2.2.1 Flin-Flon-Snow Lake area (J.M. Duke)

a) Publications

1987-88

Scoates, R.F.J., Metallogeny of mafic-ultramafic rocks: Flin Flon-Snow Lake belt (Project C.2.2.1); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-9, p. 170, 1987.

1988-89

Scoates, R.F.J., Metallogeny of mafic-ultramafic rocks, Flin Flon - Snow Lake project (Project C.2.2.1); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-7, p. 174, 1988.

c) Posters

1984-85

Young, J. and Ayers, L. D., Investigations of mafic-ultramafic plutons and associated mineralization, Flin Flon - Snow Lake belt, at the Manitoba Annual Open House, Winnipeg, November 15, 1984, and at the Geological Survey of Canada, Current Activities Forum, Ottawa, January 22-24, 1985.

d) Oral Presentations

1985-86

Young, J. and Ayres, L.D., Mafic-ultramafic plutons of the Flin Flon - Snow Lake area, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

C.2.2.2 Northern Churchill (L.J. Hulbert)

a) Publications

1987-88

Hulbert, L., Metallogeny of mafic-ultramafic rocks: northern Churchill (Project C.2.2.2); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-10, p. 170, 1987.

1988-89

Hulbert, L.J., Metallogeny of mafic-ultramafic rocks, northern Churchill (Project C.2.2.2); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-8, p. 175-176, 1988.

1989-90

Hegner, E., Kyser, T.K. and Hulbert, L.J., Nd, Sr, O isotopic constraints on the petrogenesis of mafic intrusions in the Proterozoic Trans-Hudson Orogen of central Canada; Canadian Journal of Earth Sciences, v. 26, 1989 (in press).

d) Oral Presentations

1986-87

Hulbert, L.J., Platinum group element environments in the Churchill Province of northern Saskatchewan and Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 21, 1987; abstract published in Geological Survey of Canada, Paper 87-8, p. 5, 1987.

1987-88

Hegner, E. and Hulbert, L., Sm-Nd ages and origin of mafic-ultramafic intrusions from the Proterozoic Lynn Lake Domain, Manitoba, Canada, at the GAC/MAC Joint Annual Meeting, Saskatoon, May 27, 1987; abstract published in GAC/MAC 1987, Program with Abstracts, v. 12, p. 54.

C.2.2.3 Falcon Lake stock (R.F.J. Scoates)

a) Publications

1986-87

Mandziuk, W.S., Brisbin, W.C. and Scoates, R.F.J., The Falcon Lake igneous complex, southeastern Manitoba; in Trip 13: Layered Intrusions of Southeastern Manitoba and Northwestern Ontario, by R.F.J. Scoates, B.L. Williamson, J.M. Duke, W. Mandziuk, W.C. Brisbin, and R.H. Sutcliffe, GAC/MAC/CGU Field Trip Guidebook, p. 21-36, 1986.

1987-88

Scoates, R.F.J., Falcon lake Igneous Complex (Project C.2.2.3); *in* Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-11, p. 170, 1987.

1988-89

Mandziuk, W.S., Brisbin, W.C. and Scoates, R.F.J., Igneous structures in the Falcon Lake Intrusive Complex, southeastern Manitoba, Canadian Mineralogist, v. 27, part 1, p. 81-92, March 1989.

Tirschmann, P.A. and Halden, N.M., Metallogeny of mafic-ultramafic rocks, Falcon Lake Igneous Complex (Project C.2.2.3); *in* Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-9, p. 176, 1988.

c) Posters

1984-85

Mandziuk, W. and Brisbin, W.C., Geology and structure of the Falcon Lake Stock, southeastern Manitoba, *at* the Manitoba Energy and Mines Annual Open House, Winnipeg, November 15, 1984, and *at* the Geological Survey of Canada, Current Activities Forum, Ottawa, January 22-24, 1985.

1985-86

Mandziuk, W., Brisbin, W.C. and Scoates, R.F.J., Internal fabric and mineralization of the Falcon Lake Igneous Complex, *at* the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

1986-87

Mandziuk, W.S., Brisbin, W.C. and Scoates, R.F.J., The internal fabric of the Falcon Lake Igneous Complex, southeastern Manitoba, *at* the GAC/MAC/CGU Joint Annual Meeting, Ottawa, May 20, 1986; abstract published in GAC/MAC/CGU Program with Abstracts, v. 11, p. 99, 1986.

d) Oral Presentations

1986-87

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e) Theses

1988-89

Mandziuk, W.S., Primary structures of the Falcon Lake Intrusive Complex, southeastern Manitoba; unpublished M.Sc. thesis, University of Manitoba, Winnipeg, 1988.

C.2.2.4 Fox River Sill (R.F.J. Scoates)

a) Publications

1986-87

Scoates, R.F.J. and Eckstrand, O.R., Platinum-group elements in the Upper Central Layered Zone (UCLZ) of the Fox River Sill, northeastern Manitoba; Economic Geology, v. 81, p. 1137-1146, 1986.

1987-88

Scoates, R.F.J., Fox River Sill (Project C.2.2.4); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-12, p. 170-171, 1987.

1988-89

Eckstrand, O.R., Grinenko, L.N., Krouse, H.R., Paktunc, A.D., Schwann, P.L. and Scoates, R.F.J., Preliminary data on sulphur isotopes and Se/S ratios, and the source of sulphur in magmatic sulphides from the Fox River Sill, Molson Dykes, and Thompson nickel deposits, northern Manitoba; in Current Research, Part C, Geological Survey of Canada, Paper 89-1C, p. 235-242, 1989.

Schwann, P.L. and Scoates, R.F.J., Metallogeny of mafic-ultramafic rocks, Fox River sill (Project C.2.2.4); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-10, p. 176, 1988.

b) Open Files

1987-88

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c) Posters

1986-87

Scoates, R.F.J., Raudsepp, M. and Turnock, A.C., Petrochemical variations in a successive sequence of cyclic units, Upper Central Layered Zone (UCLZ), Fox River Sill, Manitoba, at the GAC/MAC/CGU Joint Annual Meeting, Ottawa, May 20, 1986; abstract published in GAC/MAC/CGU Program with Abstracts, v. 11, p. 125, 1986.

1987-88

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d) Oral Presentations

1984-85

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1985-86

Scoates, R.F.J., Platinum-group elements and chromite mineralization in the Fox River Sill and Bird River Sill, Manitoba, at Queen's University, Kingston, February 3, 1986.

1988-89

Schwann, P.L. and Scoates, R.F.J., Petrology of platinum group element mineralized units, Upper Central Layered Zone, Fox River Sill, northeastern Manitoba, at the GAC/MAC.CSPG Joint Annual Meeting, St. John's, May 25,1988; abstract published in GAC/MAC/CSPG Program with Abstracts, v. 13, p. A110, 1988.

Scoates, R.F.J., Schwann, P.L. and Eckstrand, O.R., Geochemical patterns associated with PGE mineralized units of the Fox River Sill, northeastern Manitoba, Canada, at the V.M. Goldschmidt Conference, Baltimore, Maryland, May 11-13, 1988; abstract published in V.M. Goldschmidt Conference Program and Abstracts, p. 72, 1988.

e) Theses

1988-89

Schwann, P.L., Petrography, geochemistry and platinum-group element distribution of part of the Upper Central Layered Zone, Main Layered Series, 462W section, Fox River Sill, northeastern Manitoba; unpublished M.Sc. thesis, Carleton University, Ottawa, 1989.

C.2.2.5 Bird River Sill (R.F.J. Scoates)

a) Publications

1986-87

Scoates, R.F.J., Williamson, B.L. and Duke, J.M., Igneous layering in the ultramafic series, Bird River Sill; in Trip 13: Layered Intrusions of Southeastern Manitoba and Northwestern Ontario, by R.F.J. Scoates, B.L. Williamson, J.M. Duke, W. Mandziuk, W.C. Brisbin and R.H. Sutcliffe, GAC/MAC/CGU Field Trip Guidebook, p. 1-19, 1986.

1987-88

Williamson, B.L. Bird River Sill (Program C.2.2.5); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-13, p. 171, 1987.

1988-89

Scoates, R.F.J., Metallogeny of mafic-ultramafic rocks, Bird River Sill (project C.2.2.5); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-11, p. 176, 1988.

Scoates, R.F.J., Eckstrand, O.R. and Cabri, L.J., Interelement correlation, stratigraphic variation and distribution of PGE in the ultramafic series of the Bird River Sill, Canada; in Geo-Platinum 87, edited by H.M. Prichard, P.J. Potts, J.F.W. Bowles and S.J. Cribb, Proceedings of the Geo-Platinum 87 Symposium held on 22-23 April 1987 at the Open University, Milton Keynes, U.K., p. 239-249, 1988.

b) Open Files

1987-88

Hulbert L., Duke, J.M., Eckstrand, O.R., Lydon, J.W., and Scoates, R.F.J., Bird River Sill; in Geological Environments of the Platinum Group Elements, Geological Survey of Canada, Open File 1440, p. 46-52, March 1988.

c) Posters

1984-85

Scoates, R.F.J., Duke, J.M., Thompson, S., Hawthorne, F., Watkinson, D., Talkington, R.W., Jones, P.C. and Watson, D.M., Chromite mineralogy of the Bird River Sill, at the Geological Survey of Canada, Current Activities Forum, Ottawa, January 22-24, 1985, and at the 53rd Annual Meeting and Convention of the Prospectors and Developers Association of Canada, Toronto, March 1985.

1985-86

Duke, J.M., Williamson, B.L. and Scoates, R.F.J., Chromite deposits, Bird River Sill, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

Williamson, B.L., Scoates, R.F.J. and Duke, J.M., Morphology and mineralization in the chromitiferous zone, Bird River Sill, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

1986-87

Duke, J.M., Scoates, R.F.J. and Williamson, B.L., Layer disruption in the ultramafic series of the Bird River Sill, at the GAC/MAC/CGU Joint Annual Meeting, Ottawa, MAy 20, 1986; abstract published in GAC/MAC/CGU Program with Abstracts, v. 11, p. 65, 1986.

Williamson, B.L., Schwann, P.L., Scoates, J.S., Scoates, R.F.J., Duke, J.M. and Eckstrand, O.R., The Bird River Sill: Geology of the chromitiferous zones, eastern Chrome property, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

1987-88

Williamson, B.L. and Scoates, R.F.J., Bird River Sill Project, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

d) Oral Presentations

1985-86

Scoates, R.F.J., Duke, J.M., Eckstrand, O.R. and Williamson, B.L., Layer disruption, PGE minerlaization, and the role of supercooling in the crystallization of the Bird River Sill, Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 22, 1986; abstract published in Geological Survey of Canada, Paper 86-8, p.9, 1986.

Scoates, R.F.J., Platinum-group elements in layered .tramafic complexes, at Utah Mines Limited's seminar on "Exploration in the Precambrian", Toronto, March 6, 1986.

1986-87

Scoates, R.F.J., Platinum-group elements and chromite mineralization in the Fox River Sill and Bird River Sill, Manitoba, at Queen's University, Kingston, February 3, 1986.

Scoates, R.F.J., Layer disruption, PGE mineralization and the role of supercooling in the crystallization of the Bird River Sill, Manitoba, at the Isle of Rhum, Inner Hebrides, April 21, 1986.

Scoates, R.F.J. and Eckstrand, O.R., Contrasting models of platinum-group element mineralization in two Manitoba layered intrusions, at the Victoria District Annual Meeting of the Canadian Institute of Mining and Metallurgy, Victoria, October 4, 1986, and at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

Scoates, R.F.J. and Eckstrand, O.R., Stratigraphic distribution and interelement correlation of platinum group elements in the Bird River Sill, Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 21, 1987; abstract published in Geological Survey of Canada, Paper 87-8, p. 1, 1987.

1987-88

Scoates, R.F.J., Eckstrand, O.R. and Cabri, L.J., Inter-element correlation, stratigraphic variation and distribution of PGE in the ultramafic series of the Bird River sill, Canada, at the Geo-Platinum 87 Symposium, Buckinghamshire, United Kingdom, April 24, 1987; abstract published in Geo-Platinum Symposium Abstract volume, Paper F1, 1987.

C.2.2.6 Thompson nickel belt (O.R. Eckstrand)

a) Publications

1987-88

Bleeker, W., Thompson nickel belt (Project C.2.2.6); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-14, p. 171, 1987.

1988-89

Bleeker, W., Macek, J.J., Thompson nickel belt project: Pipe pit mine (part of 63-O/8NE); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GS-21, p.111-115, 1988.

Bleeker, W. and Macek, J.J., Pipe pit mine (Sheets A, B, C, D, E, F, G and H), 1:400; Manitoba Energy and Mines Geological Services, Preliminary maps 1988T-1 to T-8, 1988.

Eckstrand, O.R., Metallogeny of mafic-ultramafic rocks, Thompson belt (Project C.2.2.6); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-12, p. 176, 1988.

1989-90

Bleeker, W., New structural-metamorphic constraints on early Proterozoic oblique collision along the Thompson nickel belt, northern Manitoba, Canada; in The Early Proterozoic Trans-Hudson Orogen, edited by J.F. Lewry and M.R. Stauffer, Geological Association of Canada Special Paper (in press).

b) Open Files

1989-90

Bleeker, W., Litho-structural map of the Thompson open pit, Thompson nickel belt, Manitoba; Geological Survey of Canada, Open File 2089, 25p., 2 figures, August 1989.

c) Posters

1986-87

Bleeker, W., Deformational history of the Thompson orebodies, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

1987-88

Bleeker, W., Structural investigations in the Thompson nickel belt, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

1988-89

Bleeker, W. and Macek, J., Geology of the Pipe No. 2 open pit, Thompson, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

d) Oral Presentations

1986-87

Eckstrand, O.R., Selenium and the source of sulphur in magmatic nickel and platinum deposits, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 21, 1987; abstract published in Geological Survey of Canada, Paper 87-8, p. 4, 1987.

1987-88

Bleeker, W., Structural - metamorphic history of the Thompson Mine; Implications for the geology of the Churchill-Superior boundary along the Thompson Nickel Belt, Manitoba, at the GAC/MAC Joint Annual Meeting, Saskatoon, May 25, 1987; abstract published in GAC/MAC 1987, Program with Abstracts, v. 12, p. 25, 1987.

3.1 GEOPHYSICAL SURVEYS

C.3.1.1 Aeromagnetic gradiometer surveys (P.J. Hood)

a) Publications

1986-87

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer survey of the Laurie Lake - Lynn Lake area, Manitoba; 1:20,000 scale aeromagnetic total field maps 21082G to 21089G; and 1:20,000 vertical gradient maps 41082G to 41089G, April 29, 1986.

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer survey of the Issett Lake-Pemichigamau Lake area, Manitoba; 1:20,000 scale aeromagnetic total field maps 21093G to 21099; and 1:20,000 scale vertical gradient maps 41093G to 41099G, April 29, 1986.

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer surveys of areas in Manitoba and Saskatchewan; including 1:50,000 combined aeromagnetic total field and VLF EM total field profiles C21090G to C21092G (Laurie Lake - Lynn Lake) and C21100G to C21103G (Issett Lake - Pemichigamau Lake); and 1:50,000 combined aeromagnetic vertical gradient and VLF EM quadrature profiles C41090G to C41092G (Laurie Lake - Lynn Lake) and C41100G to C41103G) (Issett Lake - Pemichigamau Lake), May 28, 1986.

1987-88

Ready, E.E., Gradiometer surveys (Project C.3.1.1); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-15, p. 172, 1987.

1988-89

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer surveys of the Hanson Lake, Amisk Lake, Namew Lake areas in Saskatchewan, and Root Lake, Moose Lake, Elbow Lake areas in Manitoba; including 1:20,000 scale aeromagnetic total field maps 21203G to 21247G, 21290G, 21291G, and 21367G to 21372G; 1:20,000 vertical gradient maps 41203G to 41247G, 41290G, 41291G, and 41367G to 41372G; 1:50,000 combined aeromagnetic total field and VLF EM total field profiles C21248G to C21262G, and C21292G; and, 1:50,000 combined aeromagnetic vertical gradient and VLF EM quadrature profiles C41248G to C41262G, and C41292G, December 20, 1988.

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer surveys of the Hargrave River, Moose Lake and Bisset areas, Manitoba; including 1:50,000 combined aeromagnetic (residual total field) and VLF EM total field profiles C21387G to C21394G; and, combined aeromagnetic vertical gradient and VLF EM quadrature profiles C41387G to C41394G, February 27, 1988.

Geological Survey of Canada, High resolution aeromagnetic total field and time-domain electromagnetic surveys of the MacMillan Lake, Suttie Lake and Zed Lake areas west of Lynn Lake, Manitoba; including 1:20,000 aeromagnetic total field maps 20362G to 20368G; and, 1:20,000 maps of conductors and apparent conductivity - 25042G to 25048G, February 27, 1988.

Ready, E.E., Aeromagnetic gradiometer/VLF and EM surveys (Project C.3.1.1); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-13, p. 176, 1988.

b) Open Files

1987-88

Geological Survey of Canada, Advance release of high resolution aeromagnetic total field and vertical gradiometer maps in the Sherridon-Nokomis and northern Moose Lake areas; Open File 1478, 26 maps at 1:20,000 scale, May 1987.

Geological Survey of Canada, Advance release of high resolution 1:20,000 aeromagnetic vertical gradient and total field surveys in the Flin Flon and Root Lake areas, Manitoba and Saskatchewan; Open File 1625, (28 sheets), November 1987.

c) Posters

1985-86

Hood, P.J., et al., Aeromagnetic total field and vertical gradient maps of the Lynn Lake-Laurie Lake region and Issett Lake-Pemichigamau Lake region, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

4.1 GEOCHEMICAL SURVEYS/GLACIAL PROSPECTING

C.4.1.1 Geochemical surveys (E.H.W. Hornbrook)

a) Publications

1987-88

Friske, P.W.B., and Schmitt, H.R., Geochemical surveys (Program C.4.1.1); in Report of Field Activities 1987, Manitoba Energy and Mines, Report GSC-16, p. 173, 1987.

1988-89

Schmitt, H.R. and Friske, P.W.B., Geochemical surveys (Project C.4.1.1); in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-14, p. 177, 1988.

Schmitt, H.R., A preliminry report on the distribution of gold in lake sediments and surficial materials at Foster Lake Manitoba; in Current Research, Part C, Geological Survey of Canada, Paper 89-1C, p. 255-262, 1989.

b) Open Files

1985-86

Regional lake sediment and water geochemical reconnaissance data, Province of Manitoba (64B); Geological Survey of Canada, sample location map, 19 geochemical maps, text containing field, analytical and statistical data, Open File 1103, June 27, 1985.

Regional lake sediment and water geochemical reconnaissance data, Province of Manitoba (64F); Geological Survey of Canada, sample location map, 19 geochemical maps, text containing field, analytical and statistical data, Open File 1104, June 27, 1985.

Regional lake sediment and water geochemical reconnaissance data, Province of Manitoba (64G); Geological Survey of Canada, sample location map, 19 geochemical maps, text containing field, analytical and statistical data, Open File 1105, June 27, 1985.

1986-8.

Regional lake sediment and water geochemical reconnaissance data, Manitoba, (parts of 63K, N, O); Geological Survey of Canada, Open File 1212, 84p., 22 maps at 1:250,000 scale, June 25, 1986.

Regional lake sediment and water geochemical reconnaissance data, Manitoba, (64C); Geological Survey of Canada, Open File 1287, 60 p., 4 maps at 1:250,000 scale, July 23, 1986.

Regional lake sediment and water geochemical reconnaissance data, Manitoba, (64C); Geological Survey of Canada, Open File 1288, 130 p., 3 maps at 1:250,000 scale, July 23, 1986.

1987-88

Regional lake sediment and water geochemical reconnaissance data, northeastern Manitoba (parts of 53E, F, K, L, M); Geological Survey of Canada, Open File 1358, 240 p., 25 maps at 1:250,000 scale, June 1987.

1988-89

Regional lake sediment and water geochemical reconnaissance data, Province of Manitoba (63I, parts of 63H and 63P); Geological Survey of Canada, Open File 1641, 80p., 26 maps, July 1988.

Schmitt, H.R., Geochemical results and interpretation of a lake sediment and water survey in the Lynn Lake - Leaf Rapids region, northern Manitoba (parts of NTS 64B, 64C); Geological Survey of Canada, Open File 1959, 80 p., 38 maps, March 1989.

c) Posters

1985-86

Friske, P.W. and Schmitt, H.R., Regional lake sediment and water geochemical surveys in Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

1986-87

Schmitt, R. and Friske, P.W.B., Trace element and gold anomalies in regional lake sediment and water survey of NTS 63K, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

1987-88

Friske, P.W.B. and Schmitt, H.R., Regional geochemical lake sediment and water survey, east-central Manitoba, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

1988-89

Schmitt, H.R., Gold mobilization in lake sediments, at the 8th International Symposium on Prospecting in Areas of Glaciated Terrain, Halifax, Nova Scotia, September 1988.

Schmitt, H.R., Distribution of gold in lake sediments and surficial deposits, Foster Lake, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

C.4.1.2 Glacial prospecting (R.N.W. DiLabio)

a) Publications

1986-87

Kaszycki, C.A. and DiLabio, R.N.W., Surficial geology and till geochemistry, Lynn Lake-Leaf Rapids region, Manitoba; in Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 245-256, 1986.

1987-88

DiLabio, R.N.W., and Kaszycki, C.A., Drift prospecting program (Project C.4.1.2); in Report of Activities 1987, Manitoba Energy and Mines, Report GSC-17, p. 173, 1987.

DiLabio, R.N.W., and Kaszycki, C.A., An ultramafic dispersal train and associated gold anomaly in till near Osik Lake, Manitoba; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 67-71, 1988.

Kaszycki, C.A., Suttner, W., and DiLabio, R.N.W., Gold and arsenic in till, Wheatcroft Lake dispersal train, Manitoba; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 341-351, 1988.

Nielsen, E., and DiLabio, R.N.W., Investigations of Quaternary placer occurrences in the Manigotagan area; in Report of Field Activities 1987, Manitoba Energy and Mines, Report GS-21, p. 110-112, 1987.

1988-89

Kaszycki, C.A., Drift prospecting: northwestern Manitoba, Manitoba Energy and Mines, Report of Field Activities 1988, Report GSC-15, p. 177, 1988.

b) Open Files

1985-86

Kaszycki, C.A. and DiLabio, R.N.W., Till geochemistry, Granville Lake (64C), Manitoba; Geological Survey of Canada, Open File 1204, 12 maps at 1:250,000 scale, March 1986.

Kaszycki, C.A., Way Nee, V., Nielsen, E. and DiLabio, R.N.W., Surficial geology, Granville Lake (64C), Manitoba; Geological Survey of Canada, Open File 1258, one map at 1:125,00 scale, March 1986.

1986-87

DiLabio, R.N.W. and Kaszycki, C.A., Till geochemistry, Brochet, Manitoba, (64F); Geological Survey of Canada, Open File 1205, 37p., 12 maps at 1:250,000 scale, October 1986.

1989-90

Kaszycki, C.A., DiLabio, R.N.W. and Way Nee, V.J., Surficial geology, Brochet, Manitoba (64F); Geological Survey of Canada, 1:125,000 scale map, Open File 1331, April 1989.

Kaszycki, C.A. and Way Nee, V.J., Surficial geology, Uhlman Lake, Manitoba (64B); Geological Survey of Canada, 1:250,000 scale map, Open File 2019, April 1989.

Kaszycki, C.A. and Way Nee, V.J., Surficial geology, Big Sand Lake, Manitoba (64G); Geological Survey of Canada, 1:250,000 scale map, Open File 2020, April 1989.

Kaszycki, C.A. and Way Nee, V.J., Surficial geology, Kississing, Manitoba (63N); Geological Survey of Canada, 1:250,000 scale map, Open File 2021, April 1989.

c) Posters

1985-86

Kaszycki, C.A. and DiLabio, R.N.W., Till geochemistry - Granville Lake-Brochet area, Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 22-23, 1986.

Kaszycki, C.A. and DiLabio, R.N.W., Till geochemistry of the Lynn Lake region, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985, and at the 54th Annual Meeting and Convention of the Prospectors and Developers Association of Canada, Toronto, March 10-12, 1986.

1986-87

DiLabio, R.N.W., Placer gold at Manigotagan, Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986, and at the Geological Survey of Canada Current Activities Forum, Ottawa, January 20-21, 1987, and at the 55th Annual Meeting and Convention of the Prospectors and Developers Association of Canada, Toronto, March 9-11, 1987.

DiLabio, R.N.W. and Kaszycki, C.A., Ultramafic dispersal train, Osik Lake, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

Kaszycki, C.A. and DiLabio, R.N.W., Glacial dispersal of Paleozoic carbonates in northwestern Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 20-21, 1987.

1987-88

Henderson, P.J., Kaszcki, C.A., Klassen, R.A., Shilts, W.W. and Thorleifson, L.H., Drift composition and glacial ice flow patterns beneath the central portion of the Laurentide ice sheet, at the International Union for Quaternary Research, XII International Congress, Ottawa, August 1, 1987; abstract published in INQUA 1987, Programme with Abstracts, p. 185, 1987.

Kaszycki, C.A., Carbonate dispersal till geochemistry, northwestern Manitoba, at the International Union for Quaternary Research, XII International Congress, Ottawa, August 1, 1987; abstract published in INQUA 1987, Programme with Abstracts, p. 198, 1987.

Kaszycki, C.A., Suttner, W. and DiLabio, R.N.W., Gold and arsenic in till, Wheatcroft Lake dispersal train, Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January, 1988; and at the 56th annual meeting and convention of the Prospectors and Developers Association of Canada, Toronto, March 1988.

Nielsen, E. and Kaszycki, C.A., Till geochemistry in the Ruttan area, Manitoba, at the Manitoba Energy and Mines Open House, Winnipeg, November 20, 1987.

1988-89

Kaszycki, C.A. and Nielsen, E., Surficial geology and drift prospecting, northwestern Manitoba, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

Samson, J.C., Kaszycki, C.A., Bouchard, M.A. and Delisle, C.E., Sensitivity of glacial deposits to acid precipitation in northern Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 16-18, 1989.

d) Oral Presentations

1984-85

DiLabio, R.N. and Nielsen, E., Geochemical investigations of till in the Lynn Lake area, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 15, 1984

1985-86

Kaszycki, C.A. and DiLabio, R.N.W., Sedimentology and geochemistry of surficial materials within Lake Agassiz Basin, Lynn Lake-Leaf Rapids area, Manitoba, at the Geological Survey of Canada Cuurent Activities Forum, Ottawa, January 22, 1986; abstract published in Geological Survey of Canada, Paper 86-8, p. 9, 1986.

1987-88

Kaszycki, C.A., Carbonate dispersal and till geochemistry, northwestern Manitoba, at the 89th Annual General Meeting of the Canadian Institute of Mining and Metallurgy, Toronto, May 5, 1987; abstract published in CIM Bulletin, v. 80, no 899, p. 66, 1987.

Kaszycki, C.A., Till composition and drift prospecting in northwestern Manitoba, at the University of Quebec at Montreal (UQAM), graduate seminar in geochemical exploration using glacial till, February 1988.

Kaszycki, C.A., MDA drift prospecting programs in northwestern Manitoba, at the meetings of the Flin Flon and Thompson local sections of the Canadian Institute of Mining and Metallurgy (CIM), February 1988.

Kaszycki, C.A., Till composition and glacial dispersal: Influence on the resolution of geochemical anomalies, at the 56th Annual General Meeting and Convention of the Prospectors and Developers Association of Canada, March 9, 1988

1988-89

Kaszycki, C.A., Late Wisconsinan ice flow history, northwestern Manitoba, at the GAC/MAC/CSPG Joint Annual Meeting, St. John's, May 24, 1988; abstract published in GAC/MAC/CSPG Program with Abstracts, v. 13, p. A64, 1988.

Kascycki, C.A., Till studies and drift prospecting: Darrol Lake and southern Kississing Lake, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

e) Theses

1986-87

Samson, J., Contamination du sol par les metaux lourdes venant d'un complexe metallurgique a Flin Flon (Manitoba); thèse B.Eng. non publiée, Université Laval, 1986.

Suttner, W.C., Geochemistry, mineralogy and grain size of Lake Agassiz clays: Relations to weathering processes and provenance; unpublished B.Sc. thesis, University of Ottawa, Ottawa, 1986.

1988-89

Mongrain, A., Placer gold in a quaternary beach deposit, Manigotagan, Manitoba; unpublished B.Sc. thesis, University of Ottawa, Ottawa, 1988.

1989-90

Samson, J., Sensiblite aux precipitations acides des sediments d'origine glaciaire au nord du Manitoba; thèse M.Sc. A. non publiée, Universite de Montreal, Ecole Polytechnique, Montreal, Québec, 1989.

Suttner, W.C., Glacial dispersal of gold and arsenic from an unknown source near Wheatcroft Lake, Manitoba, including reference to overlying Lake Agassiz clay; unpublished M.Sc. thesis, McGill University, Montreal, 1989.

5.1 ATLAS COMPILATION

C.5.1.1 Manitoba-north of 52° latitude (R.N.W. DiLabio)

a) Publications

1988-89

Clarke, M.D., Surficial geology, Stull Lake, Manitoba (53K) (1:250,000 scale); Geological Survey of Canada, Map 1672A, October 1988.

Clarke, M.D., Surficial geology, Norway House, Manitoba (63H) (1:250,000 scale); Geological Survey of Canada, Map 1671A, December 1988.

Clarke, M.D., Surficial geology, Oxford House, Manitoba (53L) (1:250,000 scale); Geological Survey of Canada, Map 1673A, December 1988.

1989-90

Clarke, M.D., Surficial geology, Gods River, Manitoba (53N) (1:250,000 scale); Geological Survey of Canada, Map 1684A, August 1989.

b) Open Files

1985-86

Clarke, M.D., Surficial geology, Stull Lake (53K), Manitoba; Geological Survey of Canada, Open File 1226, 2 maps at 1:250,000 scale, January 1986.

Clarke, M.D., Surficial geology, Oxford House (53L), Manitoba; Geological Survey of Canada, Open File 1227, 2 maps at 1:250,000 scale, January 1986.

1988-89

Clarke, M.D., Surficial geology, Flin Flon, Reed Lake, Rocky Lake, Cormorant Lake, Manitoba-Saskatchewan (63K); Geological Survey of Canada, Open File 1900, 4 maps (1:250,000 scale), September 1988.

1989-90

Clarke, M.D., Surficial geology, northeastern Manitoba (53 D, E, F, K, L, N, O, 54 A, B, G and 63 A, H); Geological Survey of Canada, Open File 2083, 2 maps (1:50,000 scale), August 1989.

c) Posters

1987-88

Clarke, M.D., Surficial geology mapping using landsat and space shuttle acquired imagery, Oxford House, Manitoba, at the International Union for Quaternary Research, X11 International Congress, Ottawa, August 1987; abstract published in INQUA '87, Programme with Abstracts, p. 144.

Clarke, M.D., Surficial geology atlas compilation, Manitoba-north of 52° (Project C.5.1.1), at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20, 1987; abstract published in Report of Activities 1987, Manitoba Energy and Mines, Report GSC-18, p. 174, 1987.

1988-89

Clarke, M.D., Surficial geology atlas compilation, Manitoba - north of 52° (Project C.5.1.1), at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988; abstract published in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-16, p. 177, 1988.

C.6.1.2 Co-ordination of federal geoscience program (A.G. Galley)

a) Publications

1987-88

Galley, A.G., Introductory Review; in Report of Field Activities 1987, Manitoba Energy and Mines, p. 167, 1987.

1988-89

Galley, A.G., Progress Report; in Report of Field Activities 1988, Manitoba Energy and Mines, Report GSC-1, p.169, 1988.

c) Posters

1984-85

Mineral Development Program Office, Index map showing location of GSC projects within Manitoba MDA during 1984-85, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 15, 1984.

1985-86

Mineral Development Program Office, Index map showing location of GSC projects within Manitoba MDA during 1985-86, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985.

1986-87

Mineral Development Program Office, Index map showing location of GSC projects within Manitoba MDA during 1986-87, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

1987-88

Mineral Development Program Office, Index map showing location of GSC projects within Manitoba MDA during 1987-88, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20, 1987.

1988-89

Mineral Development Program Office, Index map showing location of GSC projects within Manitoba MDA during 1988-89, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

d) Oral Presentations

1984-85

Findlay, D.C., Geoscience program implemented by the GSC in Manitoba during 1984-85, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 15, 1984.

1985-86

Galley, A.G., Geoscience program implemented by the GSC in Manitoba during 1985-86, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 19-20, 1985

1986-87

Galley, A.G., Geoscience program implemented by the GSC in Manitoba during 1986-87, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20-21, 1986.

1987-88

Galley, A.G., Geoscience program implemented by the GSC in Manitoba during 1987-88, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 20, 1987.

1988-89

Galley, A.G., Geoscience program implemented by the GSC in Manitoba during 1988-89, at the Manitoba Energy and Mines Annual Open House, Winnipeg, November 21, 1988.

APPENDIX II
LIST OF OUTPUTS
produced by the
GEOLOGICAL SURVEY OF CANADA
DURING THE
CANADA-SASKATCHEWAN MINERAL DEVELOPMENT AGREEMENT (1984-1989)

Outputs have been divided into:

a) Publications b) Open Files c) Posters d) Oral Presentations e) Theses

1.1 MINERAL DEPOSIT AND GEOLOGICAL INVESTIGATIONS

C1.1.1 Regional correlation, gold-bearing volcanic belts, Flin Flon, southend LaRonge area (E. Froese)

a) Publications

1985-86

Ashton, K.E. and Wheatley, K., The Kisseynew Gneisses of Saskatchewan: Preliminary Report; in Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 103-105, 1985.

1986-87

Ashton, K.E., Wheatley, K.J., Moser, D., Paul, D., and Wilcox, K.H., The Kisseynew Gneisses of Saskatchewan: Update; in Summary of Investigations 1986, Saskatchewan Geological Survey, Miscellaneous Report 86-4, p. 145-148, 1986.

Ashton, K.E. and Wheatley, K.J., Preliminary report on the Kisseynew gneisses in the Kisseynew-Wildnest lakes area, Saskatchewan; in Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 305-317, 1986.

1987-88

Ashton, K.E., Wilcox, K.H., Wheatley, K.J., Paul, D., and de Tombe, J., The boundary zone between the Flin Flon Domain, Kisseynew Gneisses and Hanson Lake Block, northern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey, Miscellaneous Report 87-4, p. 131-134, 1987

1988-89

Wilcox, K.H., Investigations of Missi metasedimentary rocks in the Amisk-Welsh lakes area, Saskatchewan; in Current Research, Part C, Geological Survey of Canada, Paper 89-1C, p. 165-171, 1989.

b) Open Files

1986-87

Ashton, K.E., Preliminary geological map of the Kisseynew Gneisses between Sturgeon-West River and Kisseynew Lake, Saskatchewan (parts of 63K/13; 63L/15, 16; 63M/1; 63N/4); Geological Survey of Canada, Open File 1410, 1 map at 1:50,000 scale, February 1987.

c) Posters

1985-86

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1986-87

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Ashton, K.E., Transition from Flin Flon volcanic belt to Kisseynew gneiss belt, Saskatchewan, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 20-21, 1987.

1987-88

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1988-89

Ashton, K.E., Transition zone from the Flin Flon belt to the Kisseynew sedimentary gneiss domain, at the Saskatchewan Geological Survey Open House, Regina, November 1988.

Wilcox, K.H., Kinematic analysis of the Annabel Lake shear zone, at the Saskatchewan Geological Survey Open House, Regina, November, 1988.

d) Oral Presentations

1988-89

Ashton, K.E. and Wilcox, K.H., The Sturgeon-Weir shear zone: A thrusted boundary between the Flin Flon volcanic belt - Kisseynew Gneiss terrain and Hanson Lake block, east-central Saskatchewan, at the GAC/MAC/CSPG Joint Annual Meeting, St. John's, May 24, 1988; abstract published in GAC/MAC/CSPG Program with Abstracts, v. 13, p. A3, 1988.

C1.1.2 Flin Flon - Amisk Metallogeny (J.M. Franklin)

a) Publications

1984-85

Galley, A.G., Ames, D.E. and Franklin, J.M., Preliminary investigation of gold Occurrences in the Flin Flon-Snow Lake Belt, Manitoba and Saskatchewan; in Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 761-771, 1985.

1985-86

Galley, A.G. and Franklin, J.M., Au-Cu-W-Mo mineralization related to the Phantom Lake granite, Crieghton; in Summary of Investigations, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 99-100, 1985.

1986-87

Galley, A.G. and Franklin, J.M., Gold-tungsten-copper-molybdenum mineralization in the Phantom Lake area: Progress report; in Summary of Investigations 1986, Saskatchewan Geological Survey, Miscellaneous Report 86-4, p. 141-142, 1986.

Pearson, J.G., McDougall, F.H. and Galley, A.G., Geology and evolution of gold occurrences in the Flin Flon - Amisk Lake area, Saskatchewan; in Proceedings of the Gold in the Western Shield Symposium, edited by L.A. Clark and D.R. Francis, Canadian Institute of Mining and Metallurgy Special Volume 38, p. 399-411, 1986.

1987-88

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c) Posters

1986-87

Galley, A.G., Ames, D.E., Poulsen, K.H. and Franklin, J.M., Gold metallogeny of the southern Churchill Province, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 20-21. 1987.

1987-88

Galley, A.G. and Franklin, J.M., Display of 1:10,000 scale geological map of the Boot Lake - Phantom Lake intrusive complex, at the Saskatchewan Geological Survey Open House, Regina, November 1987.

1988-89

Galley, A.G., Gold mineralization associated wdith the Boot Lake-Phantom Lake intrusive complex, Crieghton, Saskatchewan, at the Saskatchewan Geological Survey Open House, Regina, November 1988.

d) Oral Presentations

1986-87

Pearson, J.G., MacDougall, F.H. and Galley, A.G., Geology and evolution of gold occurrences in the Flin Flon area, Saskatchewan, at the Symposium on Gold in the Western Shield, Canadian Institute of Mining and Metallurgy, September 1986.

1988-89

Galley, A.G., Some aspects of gold metallogeny in the Trans-Hudson Orogen, at the Saskatoon Branch, Canadian Institute of Mining and Metallurgy Meeting, March 1989.

e) Theses

1984-85

Middleton, T.A., The relationship between the structural setting and developement of the alteration zone at the Rio gold mine, Saskatchewan; unpublished B.Sc. thesis, University of Waterloo, Waterloo, Ontario, 1985.

C1.1.3 LaRonge Structural Studies (K.H. Poulsen)

a) Publications

1985-86

Poulsen, K.H., Ames, D.E. and Galley, A.G., Gold mineralization in the Star Lake Pluton, LaRonge belt, Saskatchewan: A preliminary Report; in Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 205-212, 1986.

Poulsen, K.H., Ames, D.E. and Galley, A.G., Structural studies of gold mineralization in the LaRonge area; in Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 96-98, 1985.

1986-87

Poulsen, K.H., Ames, D.E., and Galley, A.G., Controls on Gold Mineralization in the Star Lake Pluton, LaRonge Domain; in Summary of Investigations 1986, Saskatchewan Geological Survey, Miscellaneous Report 86-4, p. 139-140, 1986.

Poulsen, K.H., Ames, D.E. and Galley, A.G., Gold minerlaization in the Star Lake pluton, La Ronge belt, Saskatchewa: A preliminary report; in Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 205-212, 1986.

1987-88

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b) Open Files

1987-88

Ames, D.E., Poulsen, K.H., and Galley, A.G., Geology and gold deposits, Star Lake Pluton, LaRonge Domain, Saskatchewan (74A/1, 73P/16); Geological Survey of Canada, Open File 1469, 1 map at 1:10,000 scale, May 1987.

c) Posters

1984-85

Poulsen, K.H., Textural variations in the host rocks of the Star Lake gold deposit, La Ronge belt, Saskatchewan, at the Geological Survey of Canada, Current Activities Forum, Ottawa, January 22-24, 1985.

Poulsen, K.H., Deformation associated with the 21 Zone deposit, Star Lake Pluton, at the Saskatchewan Open House, Regina, November 1985, and at the Geological Survey of Canada Current Activities Forum, Ottawa, January 1985, and at the 53rd Annual General Meeting and Convention of the Prospectors and Developers Association of Canada, Toronto, March 1985.

1985-86

Ames, D.E., Galley, A.G. and Poulsen, K.H., Structural study of auriferous shear zones in the Star Lake Pluton, LaRonge, Saskatchewan, at the Saskatchewan Geological Survey Open House, Regina, November 1986.

1986-87

Poulsen, K.H., Ames, D.E. and Galley, A.G., Structural geology of gold deposits in the Star Lake Pluton, LaRonge Domain, Saskatchewan, at Gold'86 an International Symposium on the Geology of Gold Deposits, Toronto, September 28-October 1, 1986; abstract published in Gold'86 Poster Paper Abstracts, edited by A.M. Chater, p. 120-122, 1986.

1987-88

Ames, D.E., Poulsen, K.H. and Galley, A.G., Geology and structural studies of gold deposits in the northern La Ronge Domain, at the Saskatchewan Geological Survey Open House, November 1987.

Poulsen, K.H., Ames, D.E., Galley, A.G., Derome, I. and Brommecker, R., Structural studies, LaRonge and Flin Flon belts, Saskatchewan, at the Saskatchewan Geological Survey Open House, Regina, November 1987.

C1.1.4 Metallogeny of ultramafic and mafic rocks (L.J. Hulbert)

a) Publications

1985-86

Hulbert, L., Ni-Cu-PGE mineralization association with the Rottenstone Lake harzburgite-pyroxenite intrusion: Preliminary findings; in Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 101-103, 1985.

1986-87

Graham, I., Watters, B.R. and Hulbert, L., The Bassett Lake mafic intrusion: Preliminary report; in Summary of Investigations 1986, Saskatchewan Geological Survey, Miscellaneous Report 86-4, p. 150-153, 1986.

Hulbert, L., An investigation of mafic and ultramafic intrusions in northern Saskatchewan; in Summary of Investigations 1986, Saskatchewan Geological Survey, Miscellaneous Report 86-4, p. 143-144, 1986.

1987-88

Hulbert, L.J., Geological environments for platinum-group element mineralization - A brief overview; in Economic Minerals of Saskatchewan Symposium Proceedings, edited by C.F. Gilboy and L.W. Vigrass, Saskatchewan Geological Society, Special Publication no. 8, p. 33-36, 1987.

Graham, I., Watters, B.R. and Hulbert, L.J., Geology and geochemistry of the Bassett Lake Complex: Progress Report; in Summary of Investigations 1987, Saskatchewan Geological Survey, Miscellaneous Report 87-4, p. 140-147, 1987.

Hulbert, L., Investigation of mafic and ultramafic rocks, and platinum group element mineralization in northern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey, Miscellaneous Report 87-4, p. 125-130, 1987.

1988-89

Hulbert, L.J., Investigation of mafic and ultramafic rocks for nickel-copper and platinum group elements in northern Saskatchewan: Preliminary findings; in Summary of Investigations 1988; Saskatchewan Geological Survey, Miscellaneous Report 88-4, p. 152-154. 1988.

1989-90

Hulbert, L.J., Nd, Sr, and O isotopic constraints on the petrogenesis of mafic intrusions in the Proterozoic Trans-Hudson Orogen of central Canada; Canadian Journal of Earth Sciences, v. 26, no. 5, p. 1027-1035, 1989.

b) Open Files

1987-88

Hulbert, L.J., Duke, J.M., Eckstrand, O.R., Lydon, J.W., Scoates, R.F.J., Cabri, L.J. and Irvine, T.N., Rottenstone Instrusion, Saskatchewan; in Geological Environments of the Platinum Group Elements, Geological Survey of Canada, Open File 1440, p. 87-93, March, 1988.

Hulbert, L.J., Duke,, J.M., Eckstrand, O.R., Lydon, J.M., Scoates, R.F.J., Cabri, L.J. and Irvine, T.N., Nicholson Bay, Saskatchewan; in Geological Environments of the Platinum Group Elements, Geological Survey of Canada, Open File 1440, p. 105-108, March 1988.

c) Posters

1985-86

Hulbert, L.J., Investigation of mafic-ultramafic intrusions, northern Saskatchewan, at the 54th Annual General Meeting and Convention of the Prospectors and Developers Association of Canada, Toronto, March 1986.

1986-87

Hulbert, L.J., Summary of investigations of mafic and ultramafic intrusions in northern Saskatchewan, at the Saskatchewan Geological Survey Open House, Regina, November 1986.

1987-88

Graham, I., Watters, B.R. and Hulbert, L.J., The Bassett Lake mafic intrusion, at the GAC/MAC Joint Annual Meeting, Saskatoon, May 25, 1987; abstract published in GAC/MAC Program with Abstracts, v. 12, p. 49, 1987.

d) Oral Presentations

1986-87

Hulbert, L.J., An overview of platinum occurrences in northern Saskatchewan, at the Saskatchewan Geological Society Symposium on Economic Minerals of Saskatchewan, Regina, November 17-18, 1986.

Hulbert, L.J., Platinum group element environments in the Churchill Province of northern Saskatchewan and Manitoba, at the Geological Survey of Canada Current Activities Forum, Ottawa, January 21, 1987; abstract published in Geological Survey of Canada, Paper 87-8, p. 5, 1987.

1989-90

Hulbert, L.J., The U-Au-PGE association from the greater Beaverlodge area of northern Saskatchewan: A new geological environment for platinum group element minerlaization, at IAGOD's 5th International Platinum Symposium, Espoo, Finland, August 3, 1989.

Hulbert, L.J. and Paktunc, A.D., The geology and geochemistry of the Rottenstone Ni-Cu-PGE deposit, northern Saskatchewan, at IAGOD's 5th International Platinum Symposium, Espoo, Finland, August 2, 1989.

2.1 GEOPHYSICAL SURVEYS

C2.1.1 Aeromagnetic Gradiometer Surveys (E.E. Ready)

a) Publications

1985-86

Ready, E.E., Status of the GSC aeromagnetic gradiometer VLF-EM contract surveys in Saskatchewan; in Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 92, 1985.

1986-87

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer survey of the May Lake - Lower Waddy Lake Area, Saskatchewan, including 1:20,000 aeromagnetic total field maps 21104G to 21114G, and 1:20,000 vertical gradient maps 41104G to 41114G, April 29, 1986.

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer maps of the May Lake - Lower Waddy Lake area, Saskatchewan, including 1:50,000 combined aeromagnetic total field and VLF EM total field profiles C21115G to C21120G, and combined aeromagnetic vertical gradient and VLF EM quadrature profiles C41115G to C41120G, May 28, 1986.

1988-89

Geological Survey of Canada, High resolution aeromagnetic total field and vertical gradiometer surveys of the Hanson Lake, Amisk Lake, Namew Lake areas, Saskatchewan, and Root Lake, Moose Lake, Elbow Lake areas in Manitoba, including: 1:20,000 scale aeromagnetic total field maps 21203G to 21247G, 21290G, 21291G, and 21367G to 21372G; 1:20,000 scale vertical gradient maps 41203G to 41247G, 41290G, 41291G, and 41367G to 41372G; 1:50,000 scale combined aeromagnetic total field and VLF EM total field profiles C21248G to C21262G, and C21292G; and 1:50,000 combined aeromagnetic vertical gradient and VLF EM quadrature profiles C41248G to C41262G, and C41292G, December 20, 1988.

b) Open Files

1987-88

Advance release of high resolution 1:20,000 aeromagnetic vertical gradient and total field surveys in the Wildnest, Hanson Lake, Flin Flon, Amisk Lake and Namew Lake areas of Saskatchewan and Manitoba; Geological Survey of Canada, Open File 1626, November 1987.

3.1 GEOCHEMICAL SURVEYS

C3.1.1 Orientation, Regional and Follow-up Geochemical Surveys (E.H. Hornbrook)

a) Publications

1985-86

Friske, P.W.B.; Regional reconnaissance geochemical lake sediment and water surveys, central Saskatchewan; in Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 93, 1985.

Schmitt, H.R., Geochemical follow-up studies of gold in lake sediments, east central Saskatchewan; in Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4, p. 94-95, 1985.

1986-87

Friske, P.W.B., Regional reconnaissance geochemical lake sediment and water surveys, north-central Saskatchewan; in Summary of Investigations 1986, Saskatchewan Geological Survey, Miscellaneous Report 86-4, p. 128, 1986.

1987-88

Schmitt, H.R. and Friske, P.W.B., Regional geochemical surveys and gold in lake sediment investigations in Saskatchewan; in Economic Minerals of Saskatchewan Symposium Proceedings, edited by C.F. Gilboy and L.W. Vigrass, Saskatchewan Geological Society Special Publication no. 8, p. 66-77, 1987

b) Open Files

1984-85

Regional lake sediment geochemical reconnaissance data, Saskatchewan (NTS 63M, 64D and parts of 63K, L, N; 73I, O, P and 74A); Geological Survey of Canada, Open File 1129, consisting of 4 sample location maps; 4 gold value maps; a text of all field, analytical and statistical data from this and the previous Open Files (266 & 488); and a preliminary interpretation of the gold data, May 28, 1985.

Regional lake sediment and water geochemical reconnaissance survey, Province of Saskatchewan (NTS 64E, and parts of 74A and 74H); Geological Survey of Canada, Open File 1106, consisting of a location map, 19 geochemical maps and text containing field, analytical and statistical data, June 25, 1985.

1986-87

Regional lake sediment and water geochemical reconnaissance data, Saskatchewan (Parts of 73P; 74A, B, C); Geological Survey of Canada, Open File 1213, 7 p., 20 maps, scale 1:250,000, June 1986.

1987-88

Regional lake sediment and water geochemical reconnaissance data, northern Saskatchewan (parts of 74A, B, G, H); Geological Survey of Canada, Open File. 1359, 122 p., 21 maps, July 3, 1987.

1988-89

Regional lake sediment and water geochemical reconnaissance data, Province of Saskatchewan (parts of 74C and 74F); Geological Survey of Canada, 100p., 44 maps, Open File 1642, August 2, 1988.

Regional lake sediment and water geochemical reconnaissance data, Province of Saskatchewan (64E, parts of 74A and 74H); Geological Survey of Canada, 120 p., 47 maps, Open File 1643, August 2, 1988.

Regional lake sediment and water geochemical reconnaissance data, Province of Saskatchewan (parts of 73O, 73P, 74A, 74B and 74C); Geological Survey of Canada, 120 p., 47 maps, August 2, 1988.

c) Posters

1986-87

Friske, P.W.B. and Schmitt, H.R., Regional lake sediment and water surveys in Saskatchewan, at the Saskatchewan Geological Survey Open House, Regina, November 1986.

Schmitt, H.R., Geochemical follow-up investigation for gold in lake sediments: La Ronge Belt, Saskatchewan, at the Saskatchewan Geological Survey Open House, Regina, November 1986.

1987-88

Schmitt, H.R. and Friske, P.W.B., Regional lake sediment and water surveys in Saskatchewan, at the Saskatchewan Geological Survey Open House, November 1987.

d) Oral Presentations

1986-87

Schmitt, H.R. and Friske, P.W.B., Regional geochemical surveys and gold in lake sediment investigations in Saskatchewan, at the Saskatchewan Geological Society Symposium on Economic Minerals of Saskatchewan, Regina, November 17-18, 1986

C4.1.2 Co-ordination of Federal Geoscience Program (A.G. Galley)

c) Posters

1984-85

Mineral Development Program Office, Index map showing location of GSC projects within Saskatchewan MDA during 1984-85, at the Saskatchewan Geological Survey Annual Open House, Regina, November 1984.

1985-86

Mineral Development Program Office, Index map showing location of GSC projects within Saskatchewan MDA during 1985-86, at the Saskatchewan Geological Survey Annual Open House, Regina, November 1985.

1986-87

Mineral Development Program Office, Index map showing location of GSC projects within Saskatchewan MDA during 1986-87, at the Saskatchewan Geological Survey Annual Open House, Regina, November 1986.

1987-88

Mineral Development Program Office, Index map showing location of GSC projects within Saskatchewan MDA during 1987-88, at the Saskatchewan Geological Survey Annual Open House, Regina, November 1987.

d) Oral Presentations

1984-85

Findlay, D.C., Geoscience projects implemented by the GSC in Saskatchewan during 1984-85, at the Saskatchewan Geological Survey Open House, Regina, November 1984.

1985-86

Galley, A.G., Geoscience projects implemented by the GSC in Saskatchewan during 1985-86, at the Saskatchewan Geological Survey Open House, Regina, November 1985.

1986-87

Poulsen, K.H., Geoscience projects implemented by the GSC in Saskatchewan during 1986-87, at the Saskatchewan Geological Survey Open House, Regina, November 1986.

1987-88

Galley, A.G., Geoscience projects implemented by the GSC in Saskatchewan during 1987-88, at the Saskatchewan Geological Survey Open House, Regina, November 1987.

1988-89

Galley, A.G., Geoscience projects implemented by the GSC in Saskatchewan during 1988-89, at the Saskatchewan Geological Survey Open House, Regina, November 1988.